ESSENTIALS OF NUTRITION

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Essentials of Nutrition

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PREFACE

The purpose of this book is to offer its readers a thoroughly adequate and up-to-date view of the essentials of nutrition.

We hope that it will be found useful both to those who do and those who do not expect to proceed later to a more detailed, professional study of nutrition and dietetics. It assumes no prerequisite training in science. Special care has therefore been given to the mode of dealing with such terms as nutrition uses in common with other sciences, and such as are just now in course of becoming everyday words. Recognizing that the effectiveness of the text depends largely upon freedom from interruption by formal definitions, we have sought rather to introduce each scientific term only as its employment becomes clearly useful, and then functionally. For cases in which more dictionary-like definitions may also be useful, a glossary is provided in the Appendix.

It is realized that at present the teaching of nutrition, like the scientific subject matter itself, is in a rapidly developing stage. It is hoped that this text will contribute to this development, and that its use will enable the teacher more readily to meet the demands of the growth of fundamental scientific knowledge of nutrition within the time-limits of the non-technical course.

The present approach to the facts and principles of the science of nutrition is mainly through the relations of food to health and efficiency. Chief prominence is given to the case of the normal young person such as the majority of the readers of this book will presumably be; though the concluding chapters take up also the problems of food for family groups, and of making nutritional knowledge more widely effective. Most of the Exercises at the ends of the chapters are, like the text itself, put in terms of the student's own experience and objectives. The Exercises and Suggested Readings are to be regarded as entirely optional. In many courses, no doubt, actual laboratory work will be provided instead of, or in addition

to, such Exercises. One of our main objects is to provide a textbook which leaves the teacher entirely free to design the accompanying laboratory work, or collateral reading, or both, in accordance with the circumstances and purposes of the particular course. The sequence of topics is also readily adjustable.

The subject matter of the text begins with an introductory chapter which is intended to indicate both the position of the present-day science of nutrition and its constructive aims. For many, such an advance indication of the far-reaching significance of our newest knowledge of nutrition increases the interest and effectiveness of the study. Those, however, who prefer to omit or postpone such evaluation will find it entirely feasible to make a logical beginning with the second or even with the third or fourth chapter.

Then follows the central body of the topical subject matter, treated in the order which most teachers prefer: (1) the energy aspects of nutrition, (2) the proteins and their amino acids, (3) the mineral elements, and (4) the vitamins. This is generally found the most readily teachable sequence from the viewpoint of the interrelationships of the topics. It has also another important advantage. To a noteworthy extent it corresponds with the chronological sequence in which the main aspects of the present-day science of nutrition have developed. Thus we study first the parts of our subject which have had the longest time in which to take definite shape and which can therefore be presented most simply and concisely. After this we are better prepared for the somewhat more detailed treatment which the newer subject matter of the vitamins requires if its study is to be of equal scientific soundness. Some of the most recent advances of knowledge in the vitamin field are so important, in the light which they throw upon everyday nutritional problems, that the somewhat fuller mode of exposition here finds a practical reward as well as a teaching reason.

The chapters on vitamins are so written that they may be studied in any sequence desired. The order followed in this text is the one which to us seems, in the present state of knowledge, best adapted to effective teaching.

As a further and important aid to interest, and therefore to effectiveness, the arrangement within each chapter is determined by the merits of its own subject matter, in preference to the rigid following of a fixed form.

The last four chapters deal with applications or extensions of nutrition study. Any of them may be omitted, without impairing the scientific coherence of the body of the book, when adaptation to a shorter course is desired or the teacher prefers to develop some other line of application.

The tables in the body of the text are kept short for comfortable reading. Data of food values thus used to illustrate any particular chapter, are taken as typical from among the much more numerous data tabulated in the Appendix.

For the privilege of using unpublished data in drawing our deductions, for the use of illustrative materials, and for aid in other ways, we are indebted to many scientific friends among whom acknowledgment is gratefully made to Drs. E. L. Batchelder, F. G. Benedict, L. E. Booher, C. A. Browne, H. L. Campbell, T. M. Carpenter, E. F. DuBois, Martha Eliot, C. J. Farmer, E. C. Kendall, C. G. King, H. E. Munsell, John B. Nichols, and M. S. Rose.

Additional Preface to Fourth Edition

In offering this new edition, we desire to express our high appreciation both to the users of the book for the gratifying reception accorded to it, and to the publishers for making possible this opportunity to incorporate the most recent advances in the science of nutrition, and in the movement to make this science ever more effective in the service of health and efficiency.

While the general character and scope are much the same as in the previous editions, each chapter has been carefully revised with the double objective of bringing it thoroughly up to date and of improving the clarity and conciseness of the text wherever possible. In several important instances new findings make possible clearer interpretations of earlier observations; as, for example, the quantitative requirements of individual amino acids which, together with extended consideration of the amino acid make-up of common food proteins, throw light upon the long recognized supplementary relationships between proteins, and on some of the practical problems of the protein malnutrition which afflicts large segments of the world population today.

The reading lists which, though kept relatively short, have been revised by the inclusion of authoritative review articles and recent

original research papers, serve to direct the student also beyond the scope of the present text into aspects too recent to have been confirmed as this was written, or omitted from discussion as representing too specialized an approach for the average reader whose primary interest lies in the practical problems of normal nutrition.

On the qualitative side, one new mineral element has been added to the list of known essentials, and a clearer indication of how several others function in body processes has been gained; while in the case of vitamins, understanding of the fundamental role in metabolism has grown in many instances, at the same time that a picture of how deficiency affects human beings has developed in the case of several factors hitherto clearly associated only with experimental animals.

Quantitative knowledge of human needs has advanced in the case of several nutritional factors; and the expert judgments expressed in the *Recommended Dietary Allowances* of the National Research Council's Food and Nutrition Board were revised in 1953. In presenting these revised recommendations we have attempted to indicate somewhat more fully than in earlier editions the bases on which they rest. In addition, we have directed our consideration to nutritional problems of elderly people and dietary recommendations for them. In view of recent medical and actuarial emphasis on the prevalence and hazards of overweight among American adults, we have considered in somewhat more detail than hitherto the question of the energy need as it is affected by various factors and the problem of the adjustment of food intake to this need in such a way as to maintain optimal body weight.

In this edition also we give prominent recognition to the firmly established fact that at least one mineral element (Chapter 8) and three vitamins (Chapters 11, 13, and 15) continue to bring increasing long-term benefits from increasingly liberal intakes up to levels at least twice those of minimal adequacy ("actual" need); so illustrating the fact that the newest chemistry of nutrition has in these most recent days "revealed much more than had been foreseen." Thus today's essentials of nutrition deal with potentialities beyond those that the science of yesterday thought possible.

We have attempted to make even more functional than hitherto the application of these facts in practical problems of food selection and preparation through such means as: (1) addition of exercises

focussing attention on the pecuniary economy of various foods as sources of needed nutrients; (2) stress on the effects of various treatments to which raw foods may be subjected on their ultimate nutritive value; and (3) addition to the tables of nutritive values of many food items in the ready-to-eat form. As concerns practical nutrition on a larger scale, the contributions and the potentialities of the Enrichment Program have been emphasized; and a section has been added on planning and implementation of worldwide nutrition programs.

In addition to the acknowledgments in the original preface, we desire to make grateful record of the generous collaboration of M. E. Bal, Alice Biester, Dr. Charles Bodecker, Grace MacLeod, Oscar E. Lanford III, Constance Pearson, J. M. Schwank, and C. M. Taylor in the preparation of later editions.

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Appendix

ESSENTIALS OF NUTRITION

1

THE NUTRITIONAL IMPROVEMENT OF LIFE

Students now enter American colleges taller and yet younger than were their parents and other predecessors when they entered the same colleges thirty to forty years ago. This is shown consistently by all the available records, and is true of both boys and girls. There has not been any known change in proportions of racial stocks which could account for the differences. The explanation is to be found not in inheritance in the biological sense but in a social inheritance,—the increase of scientific knowledge and its use in the betterment of conditions of living.

Prominent among the advances in knowledge of life and health, and resulting improvement of ways of living, has been the development of the science of nutrition and its influence upon the daily choice and use of food. The twentieth-century science of nutrition enjoys, even more than other sciences, the impetus of both the two great motive powers of modern progress: the spirit of wonder, and the spirit of service.

A generation or two ago, all the more abundant constituents of food were sufficiently known to chemists so that one might analyze a food with a satisfactory approximation to 100 per cent; yet one could not successfully nourish himself or an experimental animal with a mixture of the food constituents which analysis revealed.

Professor (later Sir) Frederick Gowland Hopkins of Cambridge University reported briefly in 1906 and fully in 1912 his experiments which made clear to students of normal nutrition that there must exist in certain foods some substance or substances not previously known, but essential to the nutritional process. He showed that laboratory animals soon ceased to thrive on mixtures of purified proteins, fats, carbohydrates, and salts even when these were

selected and proportioned in the light of all available knowledge; but that the addition of a small amount of milk, fresh or dried, or of the alcohol-extract of dried milk or of certain vegetables (but not the ashes of such foods or extracts) made the diet adequate. Figures 1 and 2 show graphically the results of typical experiments with young animals. Those experiments showed that some then unidentified alcohol-soluble organic substance or substances must function in normal nutrition. We now know that there are several such substances, some soluble in water and others in fat. Indi-

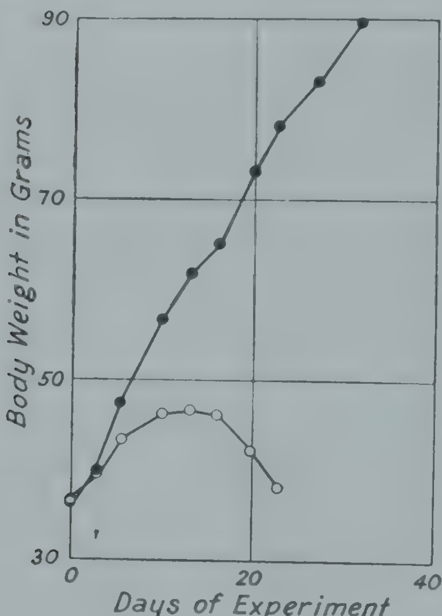

Fig. 1. Growth curves of rats in early experiments of Sir Frederick Gowland Hopkins. The lower curve represents the average body weight of a group of rats after varying intervals on an artificial diet of highly purified foodstuffs. The upper curve shows the growth of an initially similar group of rats receiving 2 or 3 cc. of milk each per day in addition to the artificial diet. (Courtesy of Sir F. Gowland Hopkins.)

vidually, they will be studied in Chapters 11–17. In the present discussion we are concerned with the general relation of this discovery and its sequel to the significance of nutrition as a factor in our understanding of nature and in the scientific management of our own lives.

For the discovery of these substances "the vitamins" has proven to be only the first step in a very far-reaching scientific development of great importance to the improvement of life.

Modern science constantly strives to make itself more and more exact. So as soon as the existence of "vitamins" was discovered, even without waiting for their complete chemical identification, studies were begun upon such quantitative questions as: (1) the relative abundance of a given vitamin in different kinds of food; (2)

the amounts needed in nutrition; and (3) the more ambitious question, how much of each gives the *best* results, i.e., what is the level of *optimal* as distinguished from merely adequate *nutritional intake.*

Our present-day realization of the importance of this latter problem is a development of much greater significance than is yet generally understood.

While this fact was revealed largely through experiments which grew out of the investigation of the newly-discovered vitamins, it

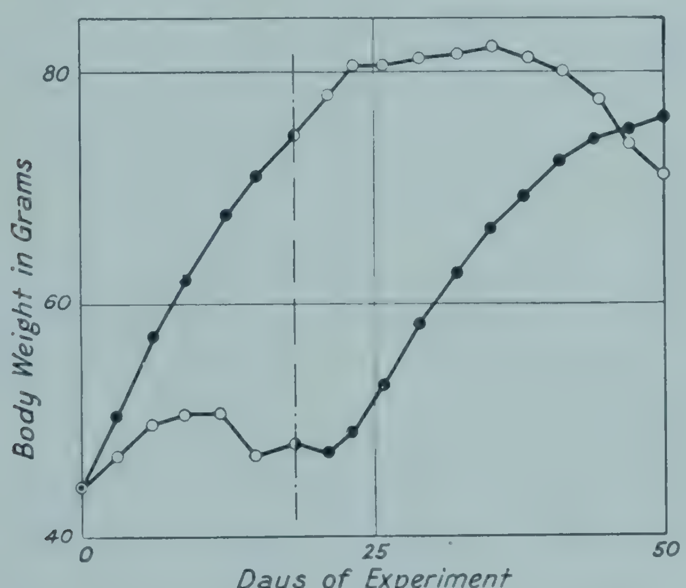

Fig. 2. Growth curves of rats in early experiments of Sir Frederick Gowland Hopkins. The lower curve represents the growth of rats receiving (up to the 18th day of the experiment) only the purified diet; the upper curve, similar rats having (up to the 18th day) 3 cc. of milk each per day in addition to this food. From the 18th day of the experiment, marked by the vertical broken line, the milk was transferred from the latter set of animals to the former. (Courtesy of Sir F. Gowland Hopkins.)

is equally true of one of the mineral elements which have long been recognized as essential to nutrition but whose far-reaching potentialities have but recently been brought fully to light. (For example, the work with different levels of calcium intake, noted in Chapter 8.)

The rapid sequence of such discoveries has been in great measure due to the increasing use of laboratory animals as instruments and reagents of nutritional research. By use of a species whose nutritional chemistry is closely similar to ours (with respect to the sub-

stance under investigation) and which runs much more rapidly than we do through its growth and development and the subsequent events of its life history, science can now study the relations between food intake, nutritional responses, and resulting health, much more comprehensively than had previously been possible.

For nearly four decades McCollum has taught that there may be important differences between the merely adequate and the optimal in nutrition. And J. F. Williams, in his teaching of personal hygiene, has emphasized that health may and should mean not merely freedom from disease but rather a positive quality of life, and that there are degrees of this positive health; though he remarked that for some years this view only slowly found wide acceptance. That acceptance of this view of health is now rapidly spreading, or, as the *Journal of the American Medical Association* has editorially phrased it, "that the difference between buoyant health and merely passable health is coming to be more appreciated," is doubtless largely due to the objective and quantitative nature of present-day nutritional research. For this gives to its findings an impersonal convincingness which advances the principle of the nutritional improvability of the normal out of the realm of opinion into that of established fact. Such nutritional improvement of already-normal health has been shown at every stage of the life cycle with statistical convincingness and conclusiveness of a very much higher order than science considers necessary to establish a physiological fact as "undoubted."

Thus notwithstanding individual (physiological) variability, the well-controlled colony of experimental animals, from which large numbers of strictly comparable individuals of known hereditary and nutritional antecedents can be drawn, becomes an instrument of research such as had not existed before. By the use of this instrument, higher precision and deeper insight both become possible, and these in turn are revealing an essentially new concept of the influence of nutrition.

To make this clear and definite, let us glance at some recent work at Columbia University where there is maintained for research of this kind a colony of laboratory-bred experimental rats in which the hereditary and nutritional background of each individual is known for so many generations as to correspond with a human population whose food supply had been known and whose blood

had been unmixed for over 2500 years. With such a colony to draw upon, strictly parallel test groups can be placed simultaneously upon the different dietaries which it is desired to compare.

In all such controlled research, we plan to introduce only one variable at a time. In nutritional problems of the sort which we are considering, the experimental variables are of two kinds: (1) individual chemical factors, elements or compounds as the case may be; and (2) the actual articles of food which nature and agriculture produce and which people obtain and consume.

In a case of the latter type, a certain basal *Diet A* showed itself adequate under the severe test of maintaining normal health with successful reproduction and rearing of young, generation after generation; yet when the proportion of milk in this food supply was doubled the resulting *Diet B* was better in that it induced a more buoyant health, or built the already-normal health to a higher level.

Whether or not the actual optimum[1] has been reached in any case, the measured differences in well-being, between the adequately nourished families on *Diet A* and their cousins who received the more scientifically balanced *Diet B*, show clearly and conclusively that our knowledge of nutrition has now entered a new era in which it can (and doubtless will) play a larger part in the attainment of a higher general level of health and efficiency than had previously been thought possible.

In the investigation just mentioned, the only experimental variable was the proportion in which the natural foods entered into the diet; but the increased proportion of milk when translated into chemical terms meant major enrichments of the diet in the three chemical factors calcium, vitamin A, and riboflavin-plus-protein which we shall study individually in Chapters 8, 15, and 13, respectively. New series of experiments were therefore begun in which these nutrients were studied independently and at successively increased levels of intake.

Here it was found that calcium, riboflavin, and vitamin A each is capable of conferring successively increased benefit at successively higher levels of intake through an unexpectedly wide range. Hitherto, it had been the accepted view (sometimes even expounded as a fundamental economic principle) that one cannot advantage-

[1] The words optimal and optimum are explained in the Glossary at the back of this book.

ously consume much more food than one actually needs; in other words that, in the case of food, the level of minimal adequacy is very nearly the optimal level of consumption. This now proves to have been an oversimplified view. A more discriminating statement is needed. Of total food as measured in calories a very small surplus above actual need *does* suffice to bring us to the optimal level of intake of *this* nutritional factor. And probably of many other factors the optimal level is only moderately higher than that of minimal adequacy, perhaps around fifty per cent higher as is commonly assumed for protein and for phosphorus in the teaching of dietetics. But for *some* factors we now find that the beneficial margins are much higher or wider.

This finding, with its consequences which we shall later study more fully, has such far-reaching significance that some have inclined to call it "a new principle of liberality in dietetics;" but it should not be confused with a merely open-handed attitude. The *principle* is one of *scientific discrimination.* What is true of calcium is *not* to be assumed to be true of other mineral elements; and what is true of vitamins A and C, and riboflavin is not to be assumed to be true for other vitamins (though it may be for some of them). The factors here discussed were not taken at random for the investigation above mentioned. They were investigated because the results of previous study pointed directly and specifically to them as probable keys to the fuller understanding of a newly discovered nutritional improvability of an already-normal condition or level of health.

Undoubtedly, hitherto, if we have appreciated the reality of degrees of positive health, we have been too fatalistic in our attitude toward it, attributing the superior vitality which some people enjoy too largely to their luck in being born with good constitutions and too little to their intelligent habits of life.

Lately, it is becoming increasingly clear that, however important the inherited constitution, there is yet a very great opportunity open to each of us to provide through sane daily living, and notably through intelligent food habits, for such a favorable internal environment[2] as shall permit our native endowments to develop and function to the best advantage.

Hopkins, speaking in the most conservative terms as President

[2] See Glossary (Appendix E).

of the Royal Society, said that "nurture can assist nature to a larger extent" than the passing generation had thought.

That differences which are really nutritional have doubtless sometimes been attributed to racial factors was emphasized by Hopkins in the leading article of the then newly established *Nutrition Abstracts and Reviews* in 1931. A community, he explained, may be found in equilibrium with an environment which includes its food supply, and the fact of such equilibrium has hitherto been taken as evidence that the environment supplies everything needed. Hence any inferiority was taken to be racial, whereas actually a racial potentiality of higher development may become manifest with an improvement in the food.

This is illustrated in the fact, repeatedly emphasized by Boas, that in immigrant families supposedly representing physically inferior racial stocks the children and grandchildren approach the typical American physique with surprising rapidity when living under American conditions.

And the fact that physique is only the most obvious and not necessarily the most important of the gains to be expected is illustrated by Dr. McLester's statement in an official address as President of the American Medical Association: that science now offers, to those who will use the newer knowledge of nutrition, greater vigor "and a higher level of cultural attainment."

Thus we are now in a new era of nutritional knowledge, in which this knowledge serves the improvement of life in two ways: (1) correctively, in the cure and prevention of deficiency diseases and of the less well recognized states of nutritional shortage or subnormality; and (2) constructively, in the improvement of already-normal health.

We can now see that the teaching of science has until recently assumed the normal internal chemistry of each species to be somewhat more rigidly specific than it really is. The newer knowledge of nutrition shows us, among other things, how our daily choice of food influences that internal environment of the body which directly environs and conditions the life process. And the new knowledge has brought a really new view.

For hitherto, while we included nutrition among environmental factors by definition, yet when we actually thought about environment it was chiefly to think about our surroundings. As we come

to realize how significantly our daily choice and use of food influences that more important environment which we carry within our own bodies, we see that we ourselves have a much larger measure of ability to improve the life process than science has hitherto supposed to be possible.

The chapters which follow will seek to make clear the essentials both of the facts of our present-day nutritional knowledge and of the functioning of this knowledge in the guidance of daily food habits and the attainment of higher health.

Some recent developments may well be mentioned at this point.

By cooperation of the Federal Department of Agriculture, a number of the State Agricultural Experiment Stations, and Cornell University, there has been established at Ithaca a laboratory for research into the nutritional interrelationships of soils, plants, farm animals, and man. Ultimately, such research may point the way to important improvement in the nutritive values of foods; and in any case should clarify the question as to how far the conditions of production do influence such nutritive values. Meanwhile the very existence of this laboratory will serve as a continuing reminder that not only genetic (hereditary) but also environmental (nutritional) influences do measurably and significantly modify the internal bodily states and thus the life processes of both plant and animal species, including our own.

At about the same time, the National Research Council reestablished its Committee on Food and Nutrition which within a year developed so greatly in response to the present-day recognition of the importance of this field that it has now been reconstituted as a Food and Nutrition Board with a number of separate but coordinated committees.

In May, 1941, there was held in Washington a large National Nutrition Conference through which wide publicity was given to the importance of food supply and of nutritional research, and to the "New Yardstick of Good Nutrition," more scientifically known as the Table of *Recommended Daily Allowances of Specific Nutrients*, or *Recommended Dietary Allowances*, issued by the National Research Council. This Table as revised in 1953 with its official explanatory footnotes is given in full in the Appendix at the back of this book. At several points in the intervening text we shall refer to these Recommended Allowances in our discussions

of specific nutrients. Carefully to be distinguished from these *Recommended Allowances* are the lower figures set up as *minimum requirements* for the special purposes of the Federal Food and Drug Administration, particularly in its regulation of the labels of foods for which "special dietary properties" are claimed. To avoid confusion we should be careful always to use the appropriate one of the conventional names italicized in the preceding sentence, rather than to speak of a "standard" or "standards" in either case.

The present book will make use of the *Recommended Allowances*, because, while attempts to ascertain minimum requirements have certain technical uses, it is *good* nutrition to which our attention is here directed, with the double goal that all our people shall be well nourished, and that wherever possible we may also build from good to better.

The goal of improvement upon hitherto accepted norms, and the fact that an element of judgment necessarily enters into the recommendations which aim at such a goal, are recognized in the following paragraph with which the Bureau of Human Nutrition and Home Economics introduced its discussion of the planning of diets by the "new yardstick":

"The Nutrition of the Nation depends in large part on the tables set by the Nation's homemakers. A new high aim for meal planning was announced during the National Nutrition Conference for Defense in May 1941. The food and nutrition committee of the National Research Council recommended dietary allowances for persons differing in age and activity. The figures rest on experimental evidence of human nutritional needs and on the careful judgment of recognized authorities in nutrition."

The United Nations has established a Food and Agriculture Organization (FAO) and a World Health Organization (WHO), which are developing worldwide nutrition programs.

EXERCISES

N. B.—While the wording of these Exercises, and those appended to other chapters, is addressed to the individual student, some involve work for instructors, or instructors and students jointly, according to circumstances.

1. Record your present height, weight, and age (dating and signing the record). Note also the age, and (if you know them correctly) the

height and weight at which you entered college. How do your height and weight compare with the normal average or standard for your age? Is your build average, or slender (linear), or stocky (lateral)?

2. Make an accurate record of the kinds of food and beverage and the amount of each which you consume (*a*) in a 24-hour day; (*b*) in each of 7 consecutive days.

3. Check the foregoing record against the accompanying U.S. Department of Agriculture Card, or such other guide as may be selected. The writers have here chosen, for reasons more fully explained beyond, a card designed primarily for young people.

Checking Card of

UNITED STATES DEPARTMENT OF AGRICULTURE
EXTENSION SERVICE
DIVISION OF COOPERATIVE EXTENSION
(Adapted)

Check Your Meals Daily for These Foods

Milk	1½ pints to 1 quart
Butter or fortified margarine	1 to 3 servings
Fruits and vegetables (interchangeable to some extent)	4 to 5 servings
A good balance is:	
1 serving potato	
1 serving citrus fruit, tomatoes, or raw cabbage	
1 serving green or yellow vegetable	
2 additional servings—fruits or vegetables (chosen according to preference and season)	
Enriched or whole-grain bread or cereals	1 to 2 servings
Eggs, meat, fish, cheese, dried beans or peas, nuts, or peanut butter (select two different kinds)	2 servings
Total liquids (water, milk, soup, fruit juices and other beverages)	2 quarts or more
Cod-liver oil (a fine supplement in winter or when you cannot afford plenty of whole milk, butter, eggs, and green-colored vegetables)	1 teaspoon

With the above, use additional bread and cereals and moderate amounts of sweets and fats to make up sufficient food energy (total calories).

(Remember that the somewhat conventional use of any such score card would lose much of its convenience if it were subject to frequent change; and

that, therefore, it can not be expected to reflect precisely the most up-to-date knowledge, and its implied judgments need not be regarded as final. Perhaps you may find reason to modify some of them as a result of your study of nutrition. Nevertheless its use may be helpful to thinking and discussion.)

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2

THE MORE ABUNDANT NUTRIENTS IN FOODS

The food as a whole nourishes the body in three ways:

(1) it furnishes the body fuels, the substances whose burning (oxidation) in the body supplies the *energy* for its activities;

(2) it provides the materials for the *building* and *upkeep* of the body tissues; and

(3) it supplies the substances by means of which the conditions and processes in the body are *regulated*, or the *precursors* from which the body makes its regulatory substances.

A *nutrient* is a substance which takes part in a nutritive function of any of these three kinds. Some nutrients function in more than one of these ways. Strictly speaking, air and water are nutrients;[1] but more commonly the body's supplies of air and water are treated rather as parts of the study of physiology and hygiene, while the study of nutrition takes them for granted and concentrates its attention upon the food supply and the fate and functions of the foodstuffs (nutrients) in the body.

An individual food may serve one, or two, or all, of the three types of function above mentioned according to the nutrient or nutrients which it contains.

This brief indication of functions will probably serve better to introduce the study of the nutrients, than would a set of formal definitions. It may, perhaps, be worth while to note at this point that the literature of nutrition uses the term "foodstuffs" in two senses. Some writers follow popular usage in making no distinction between "foodstuffs" and "foods," meaning in both cases articles

[1] Some of the early observations upon the essential function of air and the significance of respiration as related to nutrition are interestingly described in *Foundations of Nutrition*, 5th Ed., by Taylor, MacLeod, and Rose (Macmillan).

of food, or food commodities. Others use the term foodstuffs rather as a scientific term to mean the "stuffs" in the sense of the constituent or component substances of which foods are composed. When used in this latter sense, the word foodstuff becomes practically interchangeable with the word nutrient.

Because of their many important interrelations, the nutrients cannot be classified rigidly according to which of the three main types of nutritive function they serve. This will become clearer as subsequent chapters are studied. The present chapter relates chiefly to the nutrients which bulk largest in the food as a whole.

Typical examples of these constituents of foods may be illustrated in observations readily made upon milk, the one thing whose sole function in nature is to serve as food. As one receives a bottle of milk from the dealer, a partial separation of its constituents is usually already visible in the presence of a cream layer, due to the fact that the globules of *fat* which the milk contains, being lighter than the watery medium in which they float, are rising to the top. The fat of the milk may be removed by skimming-off the cream, or more quickly by means of a centrifugal separator, leaving the skimmed milk. Either whole or skimmed milk when treated with rennet or when simply allowed to sour *curdles*, the curd being due essentially to casein, the characteristic *protein* of milk. (This and other proteins will be studied briefly later in this chapter, and more fully in Chapters 6 and 19).

When the fat and the curd have been removed from milk the remaining whey, if concentrated and allowed to stand, yields crystals of *milk sugar*, which belongs, like the other sugars and the starches, to the group of substances called *carbohydrates*.

If whey residue, or if the original milk, be dried and burned there remains a mixture of mineral matters—the *ash*. In addition to water and (other[2]) mineral matters, protein, fat, and carbohydrate, milk contains citric acid, typical of the *organic acids* and most readily recognized in the citrus fruits; and soured milk contains lactic acid, the most familiar of those organic acids whose presence in foods is chiefly due to fermentation of one kind or another.

The *vitamins*, while of great importance to the nutritive value of the diet, constitute as we have seen such an elusively small frac-

[2] The science of mineralogy claims water as a mineral.

tion of the weight of any food that they are usually treated separately from the general discussions of the foodstuffs. Often, too, the minor organic constituents are either ignored or counted with the proteins, fats, or carbohydrates, whichever they most resemble. And there is another reason for postponing further consideration of the vitamins in the fact that they are *not a natural group*. Each should be studied on its own merits as in Chapters 11–17.

In what follows in this chapter we follow the order carbohydrates, fats, and proteins as being, on the whole, the most logical progression from the simpler to the more complex.

CARBOHYDRATES

Sugars and starches, with a few related substances, are grouped under the name carbohydrates. This group name was suggested by the fact that these substances are composed of carbon, hydrogen, and oxygen, and that the hydrogen and oxygen are here in the same quantitative relation to each other as in water. Of special interest to the student of nutrition are the relationships between the members of the three subdivisions of the carbohydrates as illustrated in the sections which follow.

Monosaccharides

The simplest of the carbohydrates, and the ultimate carbohydrate-units into which the more complex carbohydrates can be broken (hydrolyzed, as by digestion) are called monosaccharides. The significance of "mono" in the name is to emphasize their simplicity or "single-sugar-ness" of chemical nature (as contrasted with the disaccharides and polysaccharides to be mentioned below). Glucose, fructose, and galactose are the three monosaccharides of most importance in nutrition. These all contain six carbon atoms and are therefore known as *hexoses.*

Glucose (also called dextrose, grape sugar, corn sugar, starch sugar) is widely distributed in nature, occurring in small amounts in the blood of all animals, and much more abundantly in many fruits and plant juices. It is especially abundant in grapes, of which it often constitutes 20 per cent of the total weight or more than

half of the solid matter. Sweet corn, onions, and unripe potatoes are among the common vegetables containing considerable amounts of glucose. Pure dextrose made from cornstarch is now largely marketed as corn sugar; and it has been announced that so far as practicable corn sugar and cane sugar will receive equal treatment in the administration of the Federal Food Law.

Fructose (levulose, fruit sugar) occurs with glucose in plant juices, in fruits, and especially in honey, where it makes up about one-half of the solid matter. It is formed, along with an equal weight of glucose, when ordinary cane or beet sugar is digested.

Galactose is important because it is formed, along with an equal weight of glucose, when milk sugar is digested. It is one of the components of the cerebrosides, which are essential constituents of brain and nerve tissue.

Disaccharides

The name *disaccharide* implies a substance each molecule of which can be broken down into two monosaccharide (simple sugar) molecules. The three nutritionally important members of this group of carbohydrates are sucrose (cane or beet sugar), lactose (milk sugar), and maltose (malt sugar).

Sucrose (saccharose, cane sugar, beet sugar), which upon digestion gives one molecule of glucose and one of fructose, is present in considerable quantity in the fruits and juices of many plants. The commercial sources of sucrose are the sugar beet, the sugar and sorghum canes, the sugar palm, and the sugar maple; but many of the common fruits and vegetables contain notable amounts. For example, sucrose is said to constitute at least half the solid matter of pineapples and of some roots, such as carrots.

The per capita consumption of the practically pure cane (and beet) sugar of commerce increased rapidly for a century in the United States, dropped during the years of World War II, and then returned to the high prewar level until now it is estimated that on the average about one-seventh of our food calories are derived from this source. The question whether it is wise to take so much of a food which contributes none of the nutritionally important protein, mineral elements, and vitamins, may more profitably be discussed after the study of Chapters 6–17.

Lactose (milk sugar) occurs in the milk of all mammals, usually constituting 6 to 7 per cent of human milk and 4.5 to 5 per cent of cows' and goats' milk. When digested it yields glucose and galactose in equal proportions.

Because lactose is regarded by some physicians and bacteriologists as markedly beneficial in maintaining a desirable state of the lower intestinal tract, many persons make a special effort to secure

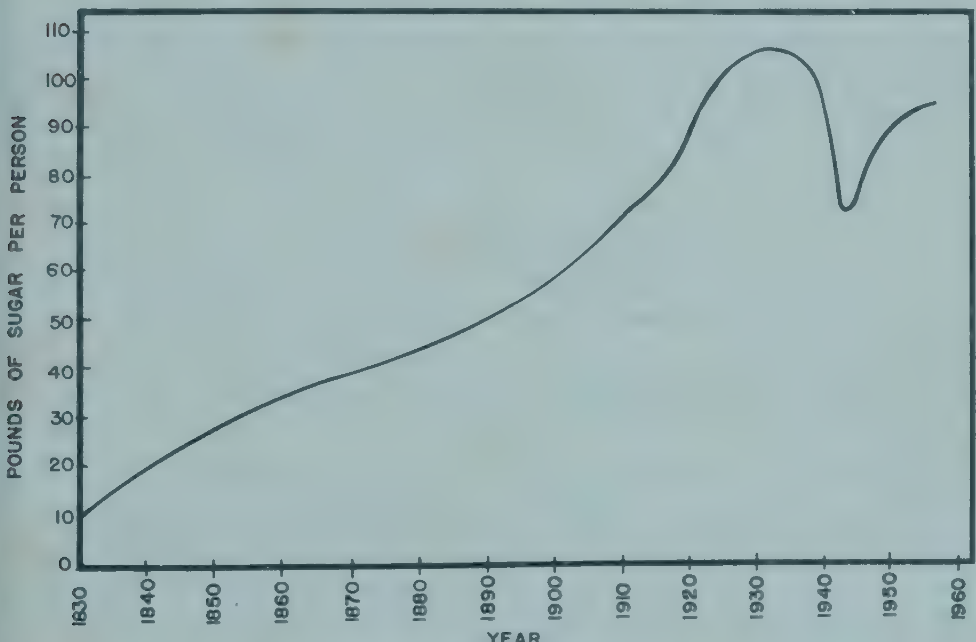

Fig. 3. Trend of the annual per capita consumption of refined sugar in the United States.

a liberal intake of this sugar, either through generous use of milk or by addition to their diet of pure lactose. As yet, the consumption of lactose in this country is far less than the amount which its dairy industry could very readily supply. The sweeter, more soluble form of this sugar is known as beta-lactose.

Maltose (malt sugar) occurs in germinating cereals, malt, and malt products. It also appears as an intermediate product when starch is digested in the body. Maltose, whether eaten as such or formed in the course of digestion, is not absorbed to any important extent, but is further broken down in the digestive tract, each molecule of maltose yielding two molecules of glucose.

Polysaccharides

Complex carbohydrates, each molecule of which represents many molecules of monosaccharides, are called *polysaccharides*. Starch, the dextrins, glycogen ("animal starch"), cellulose, and the hemicelluloses, are the only members of this group which need be mentioned here.

Starch (whose ultimate digestion-product is glucose) is the form in which plants store the largest part of their reserve carbohydrate material, and is of great importance as a constituent of many natural foods. It occurs in the seeds, roots, tubers, bulbs, and to some extent in the stems and leaves of plants. It constitutes one-half to three-fourths of the solid matter of the ordinary cereal grains, when mature, and at least three-fourths of the solids of mature potatoes. Unripe apples and bananas contain much starch which is to a large extent changed into sugars as these fruits ripen; while, on the other hand, young tender corn (maize) kernels and peas contain sugar which is transformed into starch as these seeds mature.

Each molecule of starch contains many glucose units.

Starch granules are insoluble in cold water and apparently little affected by it; on warming, however, they absorb water and swell, passing eventually into a sort of semi-solution, and in this state they are very much more easily digested than is raw starch.

In digestion, the starch of the food is changed into smaller polysaccharides, the *dextrins*, and these into the disaccharide maltose. Since, as already indicated, maltose is further digested into glucose, it is as glucose that the large quantities of carbohydrates eaten in the form of starch become available to the body.

Glycogen is very similar in chemical composition to starch, and, as it plays in some respects much the same role in animals which starch plays in plants, it is sometimes called animal starch. It occurs in many parts of the animal body, predominantly in the liver and the muscles.

Cellulose is familiar as a woody or fibrous material occurring in the cell walls of all vegetable tissues. It is a polysaccharide of glucose, more resistant than starch, and is only softened (not hydrolyzed) by cooking processes.

The *hemicelluloses* are polysaccharide-like materials which botanically resemble cellulose in belonging to the walls rather than to the contents of plant cells. Chemically, they are not so well defined as cellulose, and differ from it in yielding different monosaccharides or groups of monosaccharides and also, in some cases, socalled uronic acids, which are not sugars though related to them.

Usually a large proportion of the cellulose and hemicellulose of our food remains undigested and so gives bulk to the intestinal residue. This has some effect upon its regular movement. It is well to remember that individuals vary as to what constitutes sufficient bulk without too much roughage; and also that, not only indigestible matter, but fruits or their juices as well, may be efficient in promoting intestinal regularity.

FATS AND LIPOIDS

The Nature and Commercial Sources of Fats

Fats are composed of the same three chemical elements as are the carbohydrates, namely, carbon, hydrogen, and oxygen, but in different proportions so that fats constitute a much more concentrated form of fuel than do carbohydrates.

The true fats are chemically triglycerides, i.e., the molecule of fat yields on digestion one glycerol and three fatty acid molecules. The names applied to the individual fats generally indicate their fatty acid composition; as, for example, *tristearin*, which contains three stearic acid radicles; *oleodipalmitin*, which contains one oleic and two palmitic acid radicles; and *stearo-oleo-palmitin*, which has one radicle each of stearic, oleic, and palmitic acids.

The three fatty acids just named, with linoleic acid, are the ones which occur most abundantly in food fats generally. Others are more characteristic of particular fats, e.g., the butyric acid of butter.

A number of the fatty acids are listed with their chemical formulas in the Appendix at the back of this book.

Typical fats are not soluble in water but can be dissolved in a *fat-solvent* such as ether, "petroleum ether," chloroform, or carbon tetrachloride. In the preparation of food fats, however, solvents are rarely used. Butter is, of course, obtained by churning; and most other fats are "rendered" either by pressing the fat out of the tissue,

or by melting the fat and removing the residual tissue by settling or straining, or both.

The common commercial food fats have a wide variety of origins: butter from milk; lard and suet from meat fats; corn oil (maize oil) from the embryo of a cereal grain; peanut (arachis) and soybean oil from the seeds of leguminous plants; coconut oil, palm oil, and palm kernel oil from the seeds of palms; cottonseed and sesame oils from the seeds of other plants; olive oil from the flesh of a fruit.

Chemically there is no real distinction between fats and oils. In general, oils and fats with low melting points are characterized by a higher proportion of low molecular weight fatty acids and/or a higher proportion of unsaturated fatty acids, than are the harder fats.

TABLE 1. *Relative Amounts of Different Fatty Acids in Some Fats*

	Palmitic and Stearic	*Oleic*	*Linoleic*	*Other*
Butter	53	39		8*
Cottonseed oil	25	25	47	3
Soybean oil	7	33	52	8
Beef tallow	75	25		

* Mainly butyric.

Since American households tend to hold the traditional Northern European preference for a cooking fat of a consistency like butter, in contrast to the Southern European choice of olive oil as its chief fat, a large industry has developed in this country to convert the abundantly available vegetable oils into harder fats by the chemical introduction of hydrogen at points of unsaturation of the component fatty acids. About a billion and a half pounds of such "vegetable shortening" or "lard substitute" are processed annually.

Butter is the table fat of choice for most Americans, but, owing no doubt to its continued high cost, it is being increasingly replaced by margarine. Thus the period 1931–1951 saw a decrease in the per capita butter consumption by about one-half, while margarine use increased almost four-fold; until now fully two-thirds as much margarine as butter is consumed in this country. The manufacture of margarine involves churning fats and oils other than butterfat with milk to a butter-like texture and consistency. The fats now principally used are soybean and cottonseed oils. The final product

may be made to resemble butter in appearance by coloring it, and in nutritive value, by reenforcement with vitamin A.

Lipoids

Fats are usually accompanied by *lipoids:* fat-like substances soluble either in fat solvents or in the fat itself. *Lipids* and *lipins* are names sometimes used to cover both the true fats and the lipoids of all kinds.

Of the lipoids, the *lecithins* and *cephalins* (important members of the group known as *phospholipins*) are closely related to true fats in their chemical nature; the *cerebrosides* (or *galactolipids,* which are especially prominent in brain and nerve tissue) resemble fats to the extent of containing fatty acids; while a third important group of lipoids, the *sterols,* are "fat-like" rather in their physical properties than in their chemical nature.

Cholesterol, the longest-known of these latter, is the principal sterol of animal fats. Plant fats contain no cholesterol but other sterols known collectively as "phytosterols." The sterols are related to many biologically important products, such as the bile acids, certain of the sex hormones, and vitamin D.

Food fats, and also the socalled depot or storage fats of the body, contain relatively small though important proportions of lipoids, comprising preponderantly (perhaps 98 per cent) true fats. However, the fatty material contained in the muscles and organs of the body is much more largely made up of phospholipids and other lipoids than are the depot fats. Brain lipids, for example, are said to consist of phospholipids about one-half, cerebrosides, one-fifth to one-fourth, cholesterol, about one-fifth, with only small amounts of true fats.

Place of Fats in Nutrition and Practical Dietetics

Scientifically it has been shown that fat[3] and carbohydrate are interchangeable as body fuel throughout a very wide range of proportions. In practice, there are certain facts, partly physiological

[3] When, as in the case of the proteins, the fats, or the carbohydrates, the members of a related group admit of a generalized statement, the collective-singular form of the group name is commonly used.

and partly psychological, which tend to make the proportion of fat in the food a prominent factor in practical dietetics.

The fact that fats represent a much more concentrated source of food energy than any other class of foods is of practical importance in several ways. When wartime or other emergency requires the supplying of isolated or distant populations there is a large tonnage advantage in favor of fats, which have two and a quarter times the caloric value of proteins or carbohydrates and, unlike many other foods, can be transported dry. Similarly, its compactness as a source of food energy may commend fat for use in emergency field rations (though this is only one factor to be considered). On the other hand, our everyday habits of eating would probably have to be modified if we were to obtain all our food energy from sources other than fat, since it has been said that our digestive apparatus simply could not cope comfortably, in three meals daily, with the volume of other foods that would have to be eaten.

Another property of fat which affects our eating habits is its "staying" power, the fact that, other things being equal, the more fat a given meal contains the longer the time before it will have left the stomach. It is when the stomach is empty that the muscular contractions of its walls give rise to the "pangs" of hunger. Hence among the peoples of the Western World who have become accustomed to a fairly liberal use of fat in their daily food, any shortage of fat is felt both in the difficulty of getting the desired effects in cookery and in the fact that the low-fat meals leave the stomach more quickly so that there is more sensation of hunger before the next meal. When the physiological effect is further complicated by the anxiety accompanying a period of inadequate and uncertain food supply, the shortage of fat may become a real factor in impairment of morale.

On the other hand, food may be so rich in fat as to stay too long in the stomach, giving rise to feelings of excess if not real discomfort, and contributing to the popular view that "fatty foods are indigestible." From a physiological point of view, food fats are about as completely utilized by normal persons as are proteins or carbohydrates; it is rather the staying overlong in the stomach which gives rise to the sensations ascribed to the "indigestibility" of fat.

It has long been known that some fats are of nutritional significance as carriers of certain vitamins and their precursors. As we shall see in the chapters which deal with these vitamins, food fats vary widely in this respect.

In recent years, fats have gained recognition also in their own rights for specific nutritional functions. Thus, according to *Nutrition Reviews* for January 1955:

"The simple concept that dietary fats serve merely as convenient sources of calories and as carriers of fat-soluble vitamins has not been tenable for some time. Fats have been shown to stimulate caloric intake, increase growth rate and physical performance, improve reproduction and lactation and have other effects." It has been shown that some highly unsaturated fatty acid, such as linoleic, linolenic, or arachidonic, is a nutritionally essential part of the diet. As the quantity which the food must furnish evidently need not be large, and as these nutritionally essential fatty acids appear to be widely distributed among common foods of various types, most abundantly in the edible oils, it seems permissible to assume that ordinary everyday dietaries will supply this need without any special planning.

In 1951, the per capita consumption of food fats in the United States was estimated to be as shown in Table 2.

TABLE 2. *Consumption of Food Fats in the United States: Pounds per Capita per Year*

Butter	9.7*
Lard	12.5
Margarine	6.5*
Shortening	9.0
Edible oils	7.6
Total	41.9†

* Values for margarine and butter are weights as purchased. Only about 81 per cent of this is fat.

† Total represents fat only, the weight of water in butter and margarine being allowed for.

Since such foods as meat, milk, cheese, eggs, nuts, and so on contribute important amounts of fat to the diet, the *total* consumption of fats was probably more than three times that shown here as taken in the form of "visible" or "separated" fats. And our national food

habits seem to be shifting in the direction of a larger proportional use of fats. Thus, in the United States as a whole, there seems to have been a gradual increase in the proportion of the dietary calories which are derived from fats, from an average of 32 per cent in 1909 to about 40 per cent in 1952.[1] Some groups of the population are said to consume an even higher proportion of fat—as, for example, the business and professional men who, Durant computed, took as much as 58 per cent of their calories in the form of fat a fact which he suggested might be related to the tendency toward coronary disease in that group.

In recent years, attention has been focussed on the sterol, *cholesterol*, as the fatty material which is deposited in the arteries, liver, and kidneys with the onset of hardening of the arteries. Since, as already noted, cholesterol is the principal sterol of the fats of milk, meat, and eggs, there has been in some quarters considerable anxiety lest consumption of these foods should contribute to the undesirable accumulation of cholesterol in the body and add to the risk of hardening of the arteries and attendant ills. It now appears that the body has the ability both to build up and to destroy cholesterol, and that the principal fault, when the body accumulates excess cholesterol (or when the blood level of cholesterol rises unduly), may be excessive consumption of total calories, or of total fat, or both, rather than of cholesterol itself. Cholesterol metabolism and its relation to diet and to circulatory diseases are being actively investigated as this is written, and those interested will wish not only to study the papers cited among the Suggested Readings but to seek still later articles on the subject.

Even while recognizing that fats have other functions than as mere carriers of calories and vitamins, it appears doubtful whether such an increase as has occurred in the past 40 or 50 years in the proportion of fats in the diet of Americans, is desirable—the more so as evidence accumulates that a high fat intake is conducive to overweight, which has been called our "Number one nutrition problem."

[1] These estimates are based on the composition of food as it enters the home, and do not make allowances for the amounts wasted in food preparation or discarded at the table. To the extent that fat is particularly apt to be discarded in these ways, the figures cited may represent an overestimate of the proportion of the calories actually derived from fats.

PROTEINS

Carbohydrates and fats are the chief sources of energy for the activities of the body but not the chief constituents of which the active tissues are composed. Muscle tissue, for example, contains but little carbohydrate, and often very little fat. The chief organic constituents of the muscles, and of the protoplasm of plant and animal cells generally, are substances which contain nitrogen and sulfur in addition to the carbon, hydrogen, and oxygen of which the carbohydrates and fats are composed. In 1838, the Dutch chemist Mulder separated and described a nitrogenous material which he believed to be the fundamental constituent of tissue substances and gave it the name *protein*, derived from a Greek verb meaning "to take the first place." While Mulder's chemical work did not prove to be of permanent value, the term which he introduced has been retained, and in the plural form, proteins, is now used as a group name for a large number of different but related nitrogenous organic compounds which are so prominent among the constituents of the tissues and of food that they may still be accorded some degree of preeminence by the student of nutrition.

Any typical protein molecule is very large and complex, composed of a great number of comparatively simple units, the *amino acids*. When proteins are digested the amino acids are set free. Typically there are formed a number of intermediate products *proteoses*, *peptones*, *peptides* (corresponding to the dextrins and maltose in the digestion of starch) and ultimately the simple amino acids as final digestion products (corresponding to the monosaccharides which are the final products of the digestion of carbohydrates). Thus the relation of amino acid to protein is analogous to the relation of glucose to starch. There is, however, the important difference that the glucose molecules yielded by starch are all alike while the amino acid molecules yielded by proteins are of several different kinds.

Nutritional characteristics of the different kinds of amino acids will be studied in Chapter 6.

It is believed that in general the protein of each kind of tissue of each species of plant or animal is chemically distinct from the protein of every other tissue and species. When one considers that

each molecule of protein may contain several hundred amino-acid units of as many as twenty-one different kinds, this almost unlimited number and diversity of the proteins in nature becomes in some measure understandable.

Plants synthesize their own proteins from inorganic materials obtained from the soil and air. Animals, on the other hand, must depend, for material from which to build their tissue proteins, upon the digestion products of the proteins of their food. Some of the amino acids may be formed in the body from other amino acids or metabolites and so need not individually be furnished by the food proteins. Others, which the body cannot make from materials ordinarily available in metabolism, must be supplied in some form in the nutriment. These latter, which are frequently designated as the *indispensable* or *nutritionally essential* amino acids will be discussed more fully in the study of protein requirements in nutrition and the relative merits of different foods in meeting these requirements (Chapters 6 and 19).

DETERMINATION OF PROTEINS, FATS, AND CARBOHYDRATES IN FOODS

Actual descriptions of the methods of food analysis lie outside the scope of this book. The purpose of the paragraphs which follow is simply to indicate enough of the general plan to give a reasonable feeling of acquaintance with the meaning of the percentages as used in subsequent chapters and as tabulated in the Appendix.

Protein. Not only do all proteins contain nitrogen; they all contain not far from 16 per cent of nitrogen, and most foods contain only relatively insignificant amounts of other nitrogen compounds. Hence, to find the amount of total protein which a food contains, one may determine the amount of nitrogen and multiply this by 6.25.

Fat. A weighed portion of the air-dry, finely ground, sample of food is dried until completely water-free; then extracted with water-free ether (or other fat-solvent), the solvent evaporated, and the fat weighed.

Carbohydrate. While there are analytical methods by which each of the more important carbohydrates of our food may be de-

termined individually when necessary, it is often considered sufficient to determine total carbohydrate "by difference," i.e., by subtracting from the total percentage of organic matter in the food the percentages of protein and fat found as above.[5] This of course involves determinations of water and ash in order that the total organic matter of the food may be known.

Water is determined by drying to constant weight, and *ash* by burning off the organic matter of the dry food and weighing the residue of mineral matter. Both the operations and the interpretations require the observance of technical precautions the full discussion of which would lead us beyond the scope of this book.

Mineral elements and *vitamins* are important but are not among the more abundant nutrients in foods. Hence they are not discussed here but will be given full consideration in later chapters.

EXERCISES

1. Why are the sugar cane and the sugar beet the two economically outstanding sources of the world's supply of sugar?

2. Using the library facilities available to you, prepare an account of one or more of the following: the growing and harvesting of sugar cane or sugar beets; the making of raw sugar from cane or beets; the refining of the raw sugar into the white crystallized sugar (granulated or "domino" sugar) of commerce; the present-day corn sugar industry.

3. Distinguishing between "sugar" and "sugar and sweets," compare present per capita consumption of your country with that of others; and with those of 1900 and 1925.

4. Examine food starches under the microscope. Can you explain why corn is more frequently used for the commercial preparation of starch than wheat?

5. Look up in one of the books listed below under Suggested Readings the starch contents and the sugar contents of potatoes and sweetpotatoes. (We do not write "white and sweet potatoes," because botanically the socalled sweetpotato is not a kind of potato. They belong not only to different species but to different genera. What are their scientific names?)

6. How do potatoes and sweetpotatoes differ with respect to other nutrient factors? Is more of nutritive value lost in the making of starch from one than from the other? (Use the index; also other books.)

[5] This method includes with carbohydrate the fiber (cellulose, hemicelluloses, and lignin—which differ in availability in nutrition) and also such non-carbohydrate materials as organic acids.

7. Why have we an industry of hydrogenation of fats, which changes unsaturated into saturated fatty acids, when the "nutritionally essential" fatty acids belong to the unsaturated group?

8. Compare the cost per ounce of fat, of butter, margarine, hydrogenated shortening, and cottonseed oil.

9. Examine the recent literature for evidence as to the nutritive values of butter and margarine with respect to: (*a*) quality of the fat; (*b*) value as carrier of vitamin A value; (*c*) value as source of indispensable fatty acids; (*d*) other nutritive values.

10. Search the recent literature for present views on which unsaturated fatty acids are nutritionally essential; and indications as to the relative values of various foods as sources of these fatty acids.

11. Write a short essay on the present status of "the cholesterol problem."

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3

WHAT HAPPENS TO FOOD IN THE BODY: DIGESTION AND METABOLISM

What we have now to consider is how the foodstuffs studied in the preceding chapter are brought into the actual nutritional service of the body.

Digestion is the general name for the processes by means of which the carbohydrates, fats, and proteins of the food are brought by the body into forms fitted for absorption from its digestive tract into its true interior,—the blood and lymph, the spinal fluid, and the organs and tissues.

Metabolism (derived from a Greek word the literal meaning of which is merely "change") is used by the science of nutrition as a general name for the changes which the digestion-products undergo from the moment of their absorption until they have reached the end products of the nutritional process.

The same terms thus applied to the food as a whole may also be applied to a single kind of nutrient, as when we speak of the digestion and metabolism of carbohydrate; or of fat; or of protein.

DIGESTION

The process of digestion of the food as a whole may be said to have four general effects: (1) it brings the digestible constituents of food into fluid form; (2) it changes the more complex sugars and the starches into sugars of the simplest type, "monosaccharides;" (3) it changes at least part of the fat into a mixture of fatty acids, glycerol, and monoglycerides; (4) it changes proteins into a mixture of amino acids.

The significance of these digestive changes is of a two-fold kind. It facilitates the absorption of the nutrients; and it results in their

being absorbed in the form of their simplest "building-blocks," from which the body tissues can reconstruct carbohydrates, fats, and proteins according to their own patterns.

Or instead of rebuilding the digestion-products of the foodstuffs into the corresponding tissue-stuffs, the body may use the digestion-products as fuel.

Enzymes

The changes which the foodstuffs undergo in digestion and metabolism are facilitated and greatly hastened by the presence (in the digestive juices and in the active cells) of substances known as enzymes.

By definition, *enzymes* are catalysts formed in living cells; and *catalysts* (or *catalytic agents*) are things that "act by contact," or more particularly they are things which act very significantly in bringing about chemical changes without themselves being used up in the reaction.

In theory, such a catalyst is regarded as speeding up a change which would otherwise go on only slowly. In practice, the enzyme may make all the difference between a rapid rate of change and a rate which is infinitely slow. Hence one often speaks as if the enzyme were responsible for initiating the reaction which it catalyzes.

Thus the enzymes are characterized by their ability, even in very small amounts, to accelerate changes in other substances. The typical enzymes are *specific* both as to the substance on which each acts, often called its *substrate*, and with regard to the nature of the change which they catalyze.

Furthermore, enzymes formed in different organs of the body are apt to be at least slightly different in their own chemical nature, even in those cases in which they act in the same manner upon the same substrate. This is true, for example, of two enzymes which both take part in the normal digestion of starch, and which will serve to illustrate the modern system of naming enzymes.

By this system the name of an enzyme is constructed from the name of the substance upon which it acts, with the suffix-*ase*; and the noun thus formed is preceded by an adjective indicating the source of the enzyme. Thus in the present example, as the classical

name of starch is *amylum*, the starch-digesting enzymes are called *amylases*. The one contained in saliva is called *salivary amylase* and the one in pancreatic juice is called *pancreatic amylase*.

Enzymes which digest fats are called *lipases;* those which digest proteins are called *proteases*.

There are, however, several important instances in which names assigned before this plan of nomenclature had been decided upon still continue in common scientific use, as, for example, *pepsin* for what according to the formal system would be called *gastric protease*.

In this chapter, we shall be chiefly concerned with the enzymes which act upon food in its course through the alimentary tract. Most of these are *hydrolytic* enzymes, i.e., they accelerate processes in which the elements of water enter into the process of splitting of the foodstuffs into its digestion products. The most thoroughly studied of these digestive enzymes have all been found to be typical proteins.

A tabular summary of the best known digestive enzymes is given in the Appendix.

For our present purpose the essential point is that the digestive enzymes result in the breaking down (by hydrolysis) of the carbohydrates, fats, and proteins of the food into digestion products which (1) are more soluble and diffusible and thus more available to the body cells, and (2) are simple enough to be used readily as building-stones in the chemical architecture of the body substances, "tissue" or "regulatory," or to function readily as fuel for the support of the energy needs of nutrition.

The Course of Food through the Digestive Tract

The digestion of foodstuffs may perhaps best be studied by first tracing the course of the food as a whole through the digestive tract and then taking up in turn the fate of the carbohydrates, the fats, and the proteins, both in digestion and after absorption.

The digestive apparatus includes the *alimentary tract*,—essentially a tube about 30 feet long in a grown person,—and the *glands* whose secretions are poured into the alimentary tract and assist in the changes taking place there. The general features of the arrangement of the digestive tract are familiar to almost everyone, and are

shown diagrammatically in Fig. 4. As will appear in the discussion which follows, this system of organs is specifically adapted to perform efficiently both the *mechanical* or *physical functions* of grinding and shaking the food masses until finely divided and thoroughly mixed with the digestive juices; and also the *chemical functions* of providing digestive enzymes and surrounding them with conditions favorable to their activity.

In the course of normal digestion these functions in the different parts of the digestive system are coordinated partly through the

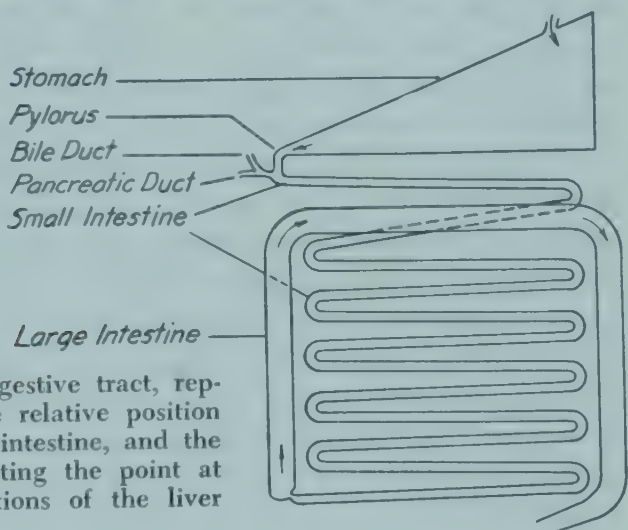

Fig. 4. Diagram of the digestive tract, representing schematically the relative position of the stomach, the small intestine, and the large intestine; and indicating the point at which the digestive secretions of the liver and the pancreas enter.

nervous system and partly by the sending ahead of "chemical messengers" (hormones) to prepare the digestive apparatus for the oncoming food material. Thus, the taste of food (or often even the thought of it) may initiate the secretion of digestive juices not only in the mouth but also in the stomach. And as soon as the stomach begins to allow the passage of the partially digested food mixture into the small intestine, a chemical messenger (called *secretin*) is sent from the intestinal membranes by way of the blood stream to the pancreas and liver, exciting these organs to increased production of secretions which are discharged into the small intestine and assist in the digestive processes there.

As indicated by the heading of this section, what follows is an account of what goes on in the successive organs of the digestive tract. The description refers, first, to the mechanical handling of the food-mass as a whole and, second, to the chemical changes

which occur in the carbohydrates, the proteins, and the fats of the food. These are, of course, the physical and chemical aspects of what the digestive tract does to the food.

In the mouth, the food should be not merely softened and lubricated so that it can be swallowed easily; it should be chewed thoroughly to reduce it to particles of the smallest size and to mix the saliva intimately through every bit of the food-mass. Only when the food has been chewed until reduced to very small particles can the different digestive juices act upon it to best advantage. In the mode of attachment of the jaw and in the strength of its muscles, we are provided by nature with an ample and efficient mechanism for the proper chewing of our food. But nature has made chewing a voluntary act; thus leaving it to our own intelligence and will to determine the thoroughness with which this first act of the digestive process shall be performed. Such rules as that one should chew a given number of times upon each mouthful may be helpful, but are too mechanical to satisfy one who takes an intelligent interest. A more rational though perhaps somewhat more extreme rule is that each mouthful should be chewed as long as any taste can be perceived or until swallowing is entirely unconscious. It is a mistake to suppose that such thorough chewing greatly reduces the amount of food required; but for other reasons it is an excellent habit.

While the food is in the mouth, several groups of salivary glands pour out their secretion upon it. This saliva is the only digestive juice which ordinarily comes directly under our observation, and perhaps because it is familiar we are apt to underestimate its significance. We say that a tempting dish "makes the mouth water," and are apt to think of this as a property of the food rather than as an important first step in digestion. The actual part played by the saliva in the process of digestion is much greater than was formerly supposed. The saliva has no appreciable action upon proteins or fats but does digest starches and dextrins by means of an enzyme known as ptyalin (or more recently as salivary amylase) which is active in approximately neutral solutions. Although relatively little chemical change in the food actually takes place in the mouth, under favorable conditions the salivary amylase may continue to act on food carbohydrates in the stomach for some time before the acid gastric secretion reaches it in sufficient amount to halt its activity.

In the stomach, the food is stored for a longer or shorter time depending largely upon the size and character of the meal. The walls of the stomach are so elastic that, as expressed by Howell, there is "never any empty space within; its cavity is only as large as its contents, so that the first portion of food eaten entirely fills it and successive portions find the wall layer occupied and are therefore received into the interior." There is thus no general circulation and mixing of the stomach contents during or immediately following a meal. This was well illustrated in an experiment in which a rat was fed a liberal meal in three courses, each course of a different color. This animal was then killed, frozen, and the stomach contents examined. The food which had been eaten first lay next to the wall of the stomach and filled the part of the stomach which connects with the intestine, while the food last eaten lay in the interior of the stomach contents near the point at which it had been pushed into the stomach by the act of swallowing. Fig. 5 represents somewhat diagrammatically the relative position of food portions in the stomach during normal digestion according to the sequence in which they were eaten.

Not much nutriment is actually absorbed from the stomach, although some such absorption occurs in the case of such things as the monosaccharides and the soluble salts of the food which as swallowed are already in the forms in which they will be absorbed. A larger factor, in the quickness with which nutriment is absorbed in any important quantity, is the promptness of its passage through the stomach and into the small intestine whose wall is a much more effective absorbing surface.

As all food masses should be thoroughly moist throughout when they are swallowed, and in the stomach are further wetted by the gastric juice, the water (or solution of foodstuffs in water) which is swallowed as such during a meal need not soak into the whole food mass in the stomach but may (and largely does) find its way along the "lesser curvature" of the stomach wall[1] from the esophagus to the pylorus, and thus pass more quickly into the small intestine than does the bulk of either the protein, the fat, or the carbohydrate of the ordinary solid food.

As in the case of any other organ, a detailed study of the func-

[1] The shape and position of the stomach are such that Fig. 5 may be regarded as about equally representative of a vertical or a horizontal section.

tions of the stomach would involve a knowledge of its structure. Omitting all but what is essential to our present purpose, we may speak of the stomach as consisting of: (1) a larger part called the *fundus* or *cardiac region,* into which the food is received when swallowed, and which is very elastic and becomes distended as the stomach stretches to accommodate more food; and (2) the *antrum* or *pyloric region,* a much smaller part, conical in shape, and ending in the *pylorus,* the muscular valve which connects the stomach with the small intestine. A region of especially thick circular muscle fibers known as the *transverse band* is considered as marking the boundary between the cardiac and the pyloric regions of the stomach. (Fig. 5.)

By mixing some harmless mineral substance such as bismuth subnitrate with the food it becomes possible to observe the contour

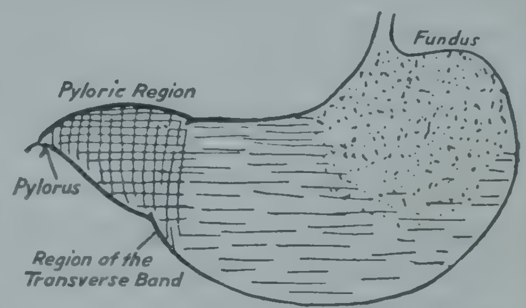

Fig. 5. Diagram of the stomach and the status of its contents during digestion. The position of the food last swallowed is here indicated by the speckled area, that of the intermediate portion of food by the horizontal shading, whereas the food first eaten, which has been pushed into the pyloric region and there thoroughly mixed with the gastric juice, is represented by the cross-hatched shading. The stomach wall is thicker and much more muscular from the region of the transverse band to the pylorus, while the wall of the fundus is relatively thin, passive, and elastic.

and movements of the food mass in the digestive tract by means of the x-ray. In this way it was shown that only in the pyloric region are the food masses and the gastric juice actively mixed by muscular contractions (see Fig. 5); in the fundus the swallowed masses of food and saliva remain comparatively undisturbed, so that in this part of the stomach the salivary digestion of starch may continue for a relatively long time.

In the region of the transverse band there is, during digestion, a rather copious secretion of strongly acid gastric juice, and it is in this same region that waves of muscular constriction are seen to originate and from which they travel toward the pylorus. But the pylorus does not open at the approach of each of these waves and

the material caught between the muscular wave and the closed pylorus is subjected to pressure and to an eddying movement which mixes it and reduces it to a creamy *chyme*. As the food thus becomes mixed with the acid secretion, salivary digestion of starch ceases; and the digestion of protein is begun by the enzyme *pepsin*, which requires an acid medium for its activity. There is also present in the gastric secretion a fat-splitting enzyme (*gastric lipase*), but its activity under the conditions usually prevailing in the stomach is rather limited. The flow of gastric juice is affected by many factors, prominent among which are appetite for the food, pleasurable sensations when the food is being chewed, freedom from emotional tension, and the presence in the stomach of certain substances including water, dilute acids, fruit and meat juices, and many other food constituents which have stimulating effects upon gastric secretion. This fact affords sound justification for the common practice of beginning a meal with a dilute (watery) yet stimulating first course such as soup or fruit.

The free hydrochloric acid of the gastric juice has not only a digestive but also an antiseptic function, for this acid is a fairly efficient germicide. If the food, by thorough chewing, has been broken into very small particles so that any bacteria which it contains are freely exposed to the gastric juice, the latter will afford a much more effective protection against the passage of objectionable bacteria through the stomach into the intestine than is possible when some of the food particles are too large to be completely permeated by the acid during the time that the acid chyme remains in the stomach.

At intervals the pylorus opens and permits the passage of chyme into the small intestine. As the food in the pyloric region is thus gradually passed out of the stomach, fresh portions of the food mass in the fundus are pressed into the antrum by the muscular tension of the stomach wall.

Thus, while the dividing line is not sharp nor prominent there is a fairly distinct difference both in structure and in function between the two regions of the stomach: in the thin-walled elastic fundus the food mass is held quietly in storage and salivary digestion of starch continues; in the thick-walled antrum with its peristaltic waves of muscular constriction the food is mixed with the gastric juice, salivary digestion ceases, peptic digestion of proteins

begins, and the food is more or less thoroughly disinfected by the free acid of the gastric juice.

The stomach as a whole may therefore be said to have four main functions. It serves: (1) as a storage reservoir receiving food in relatively large quantities, say three times a day, and passing it on to the intestine in small portions at frequent intervals; (2) as a place for the continuation of the salivary digestion of starch; and (3) for the beginning of the digestion of proteins and perhaps fats; and finally (4) as a disinfecting station of somewhat doubtful and variable value since the food is subjected to the acidity of the gastric juice for a relatively short time in the pyloric region, and the degree of contact of acid with bacteria must depend largely upon the size of the food particles at this stage of digestion.

The length of time spent by food in the stomach depends in part upon the proportions of carbohydrate, protein, and fat eaten. In experiments where each is eaten separately, protein food stays longer in the stomach than carbohydrate; fat longer than protein; and mixtures of fat and protein longest of all. In a mixed diet, then, the greater the proportion of fat the longer the food stays in the stomach. As noted in the preceding chapter, this action may be either disadvantageous or advantageous according to circumstances. Excessive fat may retard digestion unduly and lead to discomfort; on the other hand, too little fat may result in such early emptying of the stomach that hunger pangs are felt too shortly after the meal is eaten.

In the small intestine, the food, which (as we saw) has already been reduced to a liquid chyme, is subjected to the simultaneous action of three different secretions, the bile, the pancreatic juice, and the intestinal juice (or *succus entericus*). These three secretions all contain alkaline salts which quickly overcome the acidity of the chyme so that the intestinal contents as a whole are normally alkaline. The bile does not seem to exert any direct digestive action but by its solvent and dispersive action on fats and fatty acids it not only assists the fat-splitting enzymes to come into more effective contact with their substrate, but also facilitates the absorption of the fatty acids and monoglycerides formed as the result of their activity, and/or of the fat itself. Both pancreatic and intestinal juices contain digestive enzymes for each of the three groups of foodstuffs—proteins, fats, and carbohydrates. In addition there are

other specific enzymes, as, for example, those which break down nucleic acids.

In the upper part of the small intestine there occurs a special sort of muscular contraction which quickly emulsifies the fat by shaking it back and forth with alkaline juices and bile, at the same time promoting the digestion of all of the foodstuffs by bringing them into intimate association with their digestive enzymes and facilitating absorption by constantly pressing fresh portions of the digesting mixture against the intestinal wall. In addition to this peculiar movement which is characteristic of the upper part of the small intestine, there occurs throughout its length a succession of peristaltic waves of muscular constriction which force the food mass against the absorbing surface and move it onward along the digestive canal. In the wall of the small intestine there are many cross folds and innumerable tiny projections (*villi*) extending, like the fingers of a glove, into the central cavity (the *lumen*), which enormously increase the area of surface with which the digested food mixture comes into contact and facilitate the transfer of digestion-products from the lumen of the intestine to the circulating fluids of the body, the blood and the lymph. For, in addition to the reasons already suggested, every wave of muscular pressure tends to force the blood and lymph from the villi onward into the body to be replaced by fresh blood and lymph from the general circulation (and with renewed avidity for the digestion-products) as soon as the muscular wall relaxes again. The small intestine, with its abundance of enzymes and exceptionally favorable mechanical conditions, is thus well adapted to the processes of digestion and absorption and it is here that the greater part of the digestion-products of the three major groups of organic foodstuffs are absorbed. From observations on a patient whose digestive processes were apparently normal it was found that 85 per cent of the protein of the food had been absorbed before the food left the small intestine.

In the large intestine, the digestive juices continue to act upon the remnants of the foodstuffs and some further absorption of digestion products takes place, along with a very marked absorption of water. This, too, is the site of the greatest bacterial activity. Here bacteria which are normal inhabitants of the intestinal tract multiply and act upon the contents in one or more of the following ways:

(1) Certain bacteria act on the remnants of protein and protein

digestion-products to give further decomposition, of which indole and skatole in particular give feces their characteristic odor. This action is called *putrefaction*.

(2) A second action which occurs is the *fermentation* of carbohydrates. This action may be greatly increased by drinking such bacterial cultures as acidophilus milk, along with lactose and dextrins, which particularly favor the development of the desired microorganism, *Lactobacillus acidophilus*.

(3) A third type of effect may be the *breakdown of certain complex carbohydrates*. There is present in many foods a fraction, designated as "fiber" or "crude fiber," which is not attackable by any of the enzymes of the digestive tract, and which consists largely of cellulose, hemicelluloses, and lignin. It was formerly thought that this fraction was virtually unavailable as food (albeit useful as supplying needed "bulk" to the diet). It now appears that a portion of this "crude fiber" disappears in the course of passing through the intestinal tract, an effect attributed to the action of bacteria which break the carbohydrate down into products simple enough to be utilizable by the bacteria, or the body, or both. The fraction so disappearing is variable, both from food to food (depending in part on the relative amounts of the respective complex carbohydrates) and from individual to individual, apparently according to the presence of specific bacteria. In such areas of the world as some parts of the Orient, where fibrous foods constitute most of the diet and where securing enough calories for subsistence is a very real problem, the question of whether, and to what extent, the intestinal organisms convert non-digestible fiber into products the body can use, assumes practical significance.

(4) A fourth result of bacterial activity may be the *synthesis of vitamins* and perhaps other nutritionally important substances.[2] As will appear in later chapters on the individual vitamins, there is evidence that certain of these can be synthesized by the intestinal bacteria: though whether this occurs to a significant extent, and, if so, whether the body is actually able to absorb and utilize the product to any important degree, is, in most cases, still unknown.

A comparatively long time (often 18 hours or more) may

[2] A reverse effect may also occur in some circumstances, i.e., the bacteria may take for their own use some of the nutritionally important substances of the digestive contents, thereby decreasing the amount available to the host.

normally elapse between the entrance of the digestion mixture into the large intestine and the elimination of the residual material from the body. The solid excreta consist largely of crude fiber, bacteria (living and dead), residues of digestive juices, cells scraped from the wall of the intestinal tract, and (to a much smaller extent than usually realized) proteins, fats, and carbohydrates from the diet that have somehow escaped digestion or absorption.

Under normal conditions and on an average diet, the fraction of the food nutrients that escapes digestion and absorption and appears in the feces, is very small: of proteins, probably less than 8 per cent, of fats, about 5 per cent, and of carbohydrates, not more than 2 per cent.

FATE OF THE INDIVIDUAL FOODSTUFFS IN DIGESTION AND METABOLISM

The changes which some of the more prominent organic constituents of the food undergo in digestion and after absorption may now be considered individually. As a detailed treatment of the processes of intermediary metabolism would involve a somewhat technical knowledge both of organic chemistry and of physiology and require more space than is available here, we shall outline only those aspects an understanding of which is requisite to the purpose of this book, that is, the adaptation of food to the service of the body.

Carbohydrates

The carbohydrates of the food, having been brought by the digestive processes to the form of monosaccharides, are taken up from the lumen of the intestine by the cells of the intestinal mucosa and passed, so to speak, into the "physiological interior" of the body. In the process of absorption the simple sugars may become linked with phosphate. Most of the absorbed carbohydrate is transported from the intestine to the liver by way of the portal vein. In the liver, much of the carbohydrate is removed from the blood stream, glucose, fructose, and galactose each being converted into the polysaccharide *glycogen* for storage in that organ.

The glycogen which has been stored in the liver is subsequently split to yield glucose and this glucose is supplied to the blood to re-

place the carbohydrate which has been removed from it by other tissues of the body. The liver thus functions to maintain nearly constant the level of glucose in the blood of the general circulation. The concentration of carbohydrate in the liver, on the other hand, is subject to enormous variations, reaching as high as 10 per cent of the weight of the liver after an abundant meal and falling to nearly nothing when no carbohydrate food has been taken for some time.

The carbohydrate stored in the liver after a meal is thus usually converted into glucose and passes into the blood stream before the next meal, but still the glucose content of the blood remains small and nearly constant. This indicates that the glucose of the blood must be quite rapidly used, and from the standpoint of our present study, the immediate question is, What becomes of the glucose which the blood carries away from the liver? Investigation shows that this glucose disappears chiefly in the muscles. There, glucose is converted into glycogen, which may reach a concentration of 2 per cent of the weight of the muscle. This glycogen plays a part in the complicated chain of chemical reactions through which energy is released for muscular work.

Other active tissues of the body also withdraw glucose from the circulation, oxidizing it directly or indirectly as fuel for the various kinds of work which they perform.

Carbohydrate in excess of what is immediately burned and of what is stored as glycogen is converted into fat, which is a much more concentrated form of fuel and which can be stored in much larger quantity than can glycogen. Thus, under the most favorable conditions of feeding and rest, the maximum amount of glycogen stored in the entire adult body is only about two-thirds to one pound, no more carbohydrate than is frequently taken in one day's food, and only about enough, if it were the sole source of energy, to support the body for one day. Whereas, it is a matter of everyday observation that the storage of fat may reach many pounds; and a well nourished individual carries in his body enough fat to serve him as fuel for a month or more.

Fats

Before it is absorbed from the intestinal tract, some (or all) of the fat of the food is split into fatty acids, glycerol and or mono-

glycerides. This cleavage takes place through the action of fat-splitting (lipolytic) enzymes known as *lipases*. There is a lipase in the gastric secretion, but this can effectively digest only fat which has been eaten in a highly emulsified (finely subdivided) condition. The remainder of the fat, after becoming thoroughly emulsified in the small intestine by the vigorous agitation with bile and alkaline salts to which it is there subjected, is exposed to the action of the lipases in the pancreatic and intestinal juices.

There is still a wide divergence of opinion among physiologists as to how complete the splitting of fat is under usual body conditions. One group accepts the older view of Verzár that essentially all of the fat is broken down into glycerol and fatty acids before absorption; that the fatty acids, made more or less soluble by loose combination with bile salts, pass into the cells lining the small intestine, where they recombine with glycerol to form true fat; and that this fat then enters the lymph vessels. Another group follows the socalled partition theory of Frazer: that a portion of the fat is digested partially to fatty acids and monoglycerides; and that these partial digestion-products, with the bile salts, render the remaining fat sufficiently soluble that a major portion of the fat can pass undigested through the intestinal wall. Still others, though also emphasizing the prominence of monoglycerides among the end-products of fat digestion, believe that the remainder is taken up as fatty acids and glycerol (rather than as neutral fat).

In any event, the major portion of the fat eaten reappears (as fat) in the lymph vessels (rather than the blood vessels) and is finally poured with the lymph into the blood, without first having been through the liver. This results in a rise in the fat content of the blood of the general circulation which may be more marked than the increase in glucose concentration following absorption of carbohydrate. The fat thus distributed through the body may be burned in the muscles and other active tissues as a source of energy for muscular and other forms of work; or, if not needed at once as fuel, it may be deposited as body fat, a stored fuel ready to be drawn upon when needed.

Regarded as sources of energy, the functions of fat and carbohydrate are essentially the same. Furthermore, as we have seen, the body can change carbohydrate into fat to an almost unlimited extent. To what degree the body can change fat back into carbo-

hydrate, we do not know with certainty. But since, within wide limits, fat serves the same purposes as carbohydrate, our study of the uses of the foodstuffs in nutrition does not necessitate an answer to this latter question.

The fact of the essential interchangeability of fat and carbohydrate in the support of body work greatly simplifies dietary calculations, since in many cases where we deal with the energy values of foods we need not stop to consider separately how much of the energy comes from fat and how much from carbohydrate. But this fact does not justify an attitude of total indifference toward fat as a dietary constituent, for, as already mentioned in Chapter 2, fat has important specific properties.

A part of the fatty acids obtained from the fat of the diet or synthesized from carbohydrate is utilized in the formation of constituents of many of the active tissues of the body. To this limited extent at least, the fats may be regarded as tissue-building materials.

However, most of the fat of the well nourished body represents reserve fuel, and as such is deposited in the metabolically inactive adipose (fat-storing) tissues. This storage of fat may occur in many regions of the body, but is particularly marked just below the skin, where a layer of fat of variable thickness may usually be found. Stored fat is also present between the muscles and surrounding the internal organs. Fat thus deposited, although of principal significance as a reserve source of energy, may also serve the body as a mechanical protection against shocks and bruises, as a comparatively impervious blanket against the cold, and as a packing and support for certain of the organs, notably the kidneys.

Usually the nature of the fat found in the body is more or less characteristic of each species or group of closely related species. Herbivora contain as a rule harder fats than carnivora, land animals have harder fat than marine animals, and all warm-blooded animals have fats of higher melting points than those found in fishes. The nature of the body fat may also be affected by the diet. Under many conditions of feeding, the major part of the body fat may be made from carbohydrates. If, however, much of the body fat is formed from fatty acids present in the food, and if these differ markedly either in kind or in relative proportions from the mixture of fatty acids usually occurring in the fat of that species of animal, these

differences may be reflected to some extent in the kind of fat deposited in the body.

Nevertheless, although the body fat may thus differ somewhat in its chemical character, its nutritive value appears to be essentially the same. In either case, the fat thus stored may be drawn upon for use as fuel at any future time when the energy requirements of the body demand it.

Proteins

The saliva does not digest protein; and so long as the swallowed food remains in the muscularly inactive region of the stomach and unmixed with the gastric juice, the protein is unchanged. Little by little, however, as explained earlier, the food becomes mixed with the gastric juice, which contains hydrochloric acid and the proteolytic enzyme, pepsin. Together, these attack the protein of the food, changing it into the somewhat simpler, but still very complex, proteoses and peptones. The proteoses and peptones pass into the small intestine where they (and any protein which may have escaped the action of pepsin) are exposed to a whole battery of other proteolytic enzymes, including trypsin and chymotrypsin, which are provided by the pancreas and which split both native proteins and certain digestion-products to polypeptides, and a group of enzymes (partly provided by the pancreas and partly by the intestinal mucosa) which complete the breakdown to amino acids.

It has been generally believed that the hydrolysis of proteins to amino acids in the digestive tract is, in normal conditions, practically complete.[3] The protein digestion-products are absorbed, mainly from the small intestine, into the blood stream, and distributed as amino acids to the various tissues of the body. The amino acids, having been withdrawn from the blood stream by the tissues, may be used by them in various ways. (1) Part may be reassembled as building stones to form new protein in the proportions and according to the specific pattern characteristic of the tissue in question. (2) Some may be assimilated to take the place of fragments of body protein which are being broken down in the wear-and-tear

[3] A new view that proteins are absorbed and utilized partly as large peptides is under investigation (see Mellander, 1955).

processes which always go on in living cells. (3) Certain of them may be utilized in the synthesis of substances (some protein in nature, others of simpler composition) such as certain hormones and enzymes, which have essentially body-regulating rather than structural functions. (4) The remaining are broken down ("deaminized") into a nitrogenous fragment, which is eliminated from the body chiefly in the form of urea, and a non-nitrogenous residue, which is either burned as fuel, or converted into carbohydrate or fat. In serving as fuel, the protein is utilized interchangeably with carbohydrate and fat, since its energy may be converted into muscular work, internal activity, or heat.

In the growing child, there is extensive construction of new tissue and an important fraction of the food protein may be required to meet this need. Once the individual has achieved his full growth, however, there is little or no further accumulation of protein (except in special cases as, for example, in pregnancy, or during recovery after a severe wasting disease, where actual construction or reconstruction of body tissues is involved, or when, as the result of increased muscular exercise, a real enlargement of the muscles occurs). It is therefore ambiguous and may be misleading to state that the amino acids resulting from digestion of food protein may be used for purposes of tissue repair *or* be burned as fuel; for that fraction which is used in the upkeep or repair process is in general *not added* to the body's store but simply *exchanged* for an equal amount of material which is being broken down and burned.

Summary of the Fate of Foodstuffs

Carbohydrate may be
- Burned to yield energy: (*a*) for external muscular work; (*b*) for internal activity; (*c*) for heat
- Stored as glycogen
- Changed into fat

Fat may be
- Burned to yield energy: (*a*) for external muscular work; (*b*) for internal activity; (*c*) for heat
- Stored as fat
- Used in formation of tissue lipids
- Possibly to some extent changed into carbohydrate

Protein may be

Used in building or repair (upkeep) of protein tissue

Used in formation of certain hormones, enzymes, and other body regulators

Deaminized and

Burned to yield energy: (*a*) for external muscular work; (*b*) for internal activity; (*c*) for heat

Changed into carbohydrate

Changed into fat (possibly through carbohydrate).

Thus carbohydrates, fats, and proteins all serve as fuel to yield the energy of muscular and other forms of work, or to keep the body warm, and any or all of them when present in quantities more than sufficient to meet immediate needs may contribute to the production of fat which is the body's chief form of stored fuel and which is utilized in just the same way whether formed from the carbohydrate, the protein, or the fat of the food.

The body has very great power to convert one foodstuff into, or use it in place of, another; and so to economize its resources in this respect that the total energy value of the food is used to meet the total energy requirement of the body. This is of much practical importance in the planning of high and of low calorie diets. In the next chapters we shall consider the more quantitative aspects of the problem of balancing the potential energy represented by the different items of the diet against the bodily expenditure of energy in its various forms.

EXERCISES

1. Using data tabulated in the Appendix, compute the number of grams (*a*) of protein, (*b*) of fat, (*c*) of carbohydrate, consumed on each of the days for which you previously recorded your food consumption. Refer, if needed, to *Rose's Laboratory Handbook for Dietetics*, revised by Taylor and MacLeod (1949).

2. What significance do you attribute to the daily variations?

3. If your record contains any food too rare or of too artificial a nature to be included in the appended reference tables, either make adequate inquiry as to its nature and composition[4] so as to be able to complete your calculation, or amend your proposed "dietary" by the substitution of some food whose composition is better known.

[4] See, for example, the extensive table of nutritive values of cooked foods in the Appendix of Rose's *Feeding the Family*, 4th Edition (1940).

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4

ENERGY ASPECTS OF NUTRITION

Introductory Explanations

Every act and moment of life involves, in terms of formal physics, a *transformation*, or, in everyday terms, an *expenditure, of energy*.

We are fully aware of spending energy when we do active muscular work. When we rest, energy expenditure diminishes but does not stop. For, when you have relaxed as completely as you can, your body still has internal work to do. The muscular work of the heart and the work of the muscles of respiration involve significant amounts of energy within every minute; and the resting muscles still possess some degree of tension (tone or *tonus*), the maintenance of which requires a considerable energy transformation or expenditure. The internal work of the body must go on so long as life continues. It is difficult to measure any one of the forms of internal work separately from the others; but it has been estimated that the heart alone (even when the person is lying perfectly quiet) does an amount of work *each hour* equivalent to the lifting of the entire body about 100 feet into the air; and the work of breathing usually involves a considerably larger expenditure of energy; while the amount of energy expended in maintaining the tension or tonus of the muscles is larger still.

The energy which the body "spends" appears so largely in the form of heat, that the science of nutrition finds it convenient to express energy measurements in terms of the heat unit, the Calorie.

Physics makes use of two such heat units, one a thousand times greater than the other; and for brevity distinguishes the greater Calorie by writing it with a capital C while writing the lesser calorie with a small initial letter. The energy transformations in our bodies are always of such magnitude as to make the large unit the

more convenient, and it is practically always used in speaking or writing of the energy aspect of nutrition. As a technical term belonging primarily to physics, it should be written as the physicists write it, Calorie. But some writers and editors, growing weary of the frequent use of the capital, have decided that in nutrition books there is no real danger of confusion if the existence of the lesser unit be simply ignored and the initial capital dispensed with in referring to the greater calorie inasmuch as this is the only one with which we deal in nutritional discussions.

Hence in writings on nutrition the unqualified word, "calorie," will presumably mean the same as *Calorie,* i.e., the greater calorie (or kilogram-calorie or kilo-calorie) which is the *amount of heat which raises the temperature of one kilogram of water through one degree centigrade.* In this book the Calorie is given an initial capital in those cases in which an explicitly quantitative statement is being made. As a help in relating the scientific unit to our everyday measures, it may be noted that this is almost the same as the amount of heat which raises the temperature of one pound of water through four degrees Fahrenheit—or of four pounds of water through one degree Fahrenheit.

And it may also be helpful to remember that 100 Calories is about the amount of energy spent by a normal adult sitting (not *too* completely relaxed!) in a lecture room or study chair for one hour.

While the unit of energy used in discussions of food values and nutritional needs has a direct and well established physical definition, the word *energy* does not always stand simply for the mechanical concept to which the physical definition applies.

It is a current statement that: "Energy is the ability to do work." But as applied to our body and its nutritional needs, this short definition may have a double meaning, which, while it should not seriously mislead a student well grounded in even elementary physics, is in fact confusing to many people. For our bodily "ability to do work" implies, in the literal everyday meaning of the words, *both* a supply of available fuel and a properly built and conditioned "mechanism" for the transformation of the potential fuel value into the effective activities of muscles and other bodily organs. It is to the first of these that we refer when we speak of the energy aspect of nutrition and the energy values of foods; but it is to the second that we are usually referring when we say that we "feel full of

energy" or that we "lack energy." Thus the energy value of foods as expressed in calories is energy in the purely fuel or merely mechanical sense; while our *fitness* is, or is directly related to, our state of being energetic in the colloquial or psychological sense.

Mental work may cause fatigue without any corresponding energy expenditure.

The difference finds frequent illustration in the daily lives of students and teachers. Usually at the end of a lecture hour both the students and the teacher will be tired, fatigued, "lacking in energy," more or less depleted of their "ability to do work"– though probably no one "spends" (transforms) more than 100 to 150 Calories of energy in an hour in a classroom. If, then, after the lecture one goes for a walk one will probably spend twice as much energy (in the mechanical or calorie sense) in an hour, yet return feeling rested and energetic. A feeling of fatigue may be directly related to one's bodily condition without being proportional to expenditure of energy in the physical or mechanical or calorie sense. As one usually speaks, "lack of energy" will generally be due to some sub-optimal condition of one's bodily chemistry or internal environment; but not necessarily as the result of too much muscular work and energy metabolism – perhaps as a result of too little!

The Council on Foods of the American Medical Association includes among its general rules regarding advertising that the advertiser should correctly inform the public as to energy values of foods in such carefully chosen terms as to distinguish clearly between "the caloric and the popular" senses of the word *energy*, which distinction, the Council declares, "must be recognized and observed." The Council also admonishes the advertisers of food products to "take cognizance of the fact that limitation of the energy intake is essential for reduction of body weight. There are no foods that burn up body fat."

The use of the calorie as a convenient energy unit does not imply that the body is a heat engine, though this faulty analogy has been used in the past.

At the end of the nineteenth century, some teachers thought that a reasonably satisfactory approach to the essentials of nutrition as then known could be made in terms of protein and calories, and by way of the steam engine as an analogy. The protein of the food was pictured as the building material of the "mechanism;" and

the energy value of the food, as corresponding with the calorific value of the fuel burned in the engine.

But the body is so emphatically *not a heat engine* that to liken it to a steam engine is now realized to be misleadingly inadequate. Less inadequate, as well as more modern, is the analogy of the *gasoline engine* of an automobile or motorboat; for in such a motor, as in the body, the heat is a by-product or end-product and not (as in the steam engine) the means through which the potential or chemical energy of the fuel is transformed into useful work.

If, then, one desires to compare the body with an automobile engine, the protein and some of the mineral elements correspond to the structural material of the motor; other mineral matters, including water, correspond to the lubricants; such organic foods as the carbohydrates and fats and the non-nitrogenous derivatives of proteins are the fuel; and the vitamins correspond to the ignition sparks, whose own energy value is insignificant, but without which this kind of engine cannot run, however abundant its fuel and however appropriate its structural materials and its lubricants.

Throughout the present discussion of the energy aspect of nutrition, we shall be assuming (unless otherwise specifically stated) that the other nutritional requirements are being sufficiently supplied to meet normal needs, and that we are dealing with physiological rather than pathological conditions.

When one speaks of the amount of food required, it is usually the body's energy requirement, the *number of Calories needed per day,* which *first* comes to the mind of the systematic student of nutrition; for to any extent that the intake of fuel is inadequate, the body must burn some of its own substance as fuel to meet its energy needs. Hence, generally speaking, the economy of other nutritional assets is fundamentally conditioned by the meeting of the body's energy requirement.

Methods of Measuring Energy Metabolism

At the turn of the century, the outstanding news in nutrition was that about "the man in the copper box," i.e., the experiments with human subjects in the respiration calorimeter which had been developed and brought into successful use by Atwater, Rosa, and Benedict.

The respiration calorimeter, as the name implies, is both a respiration apparatus for the chemical determination of the oxygen consumed and the carbon dioxide and water produced in the respiratory exchange, and a calorimeter for the direct measurement of the heat given off by the body.

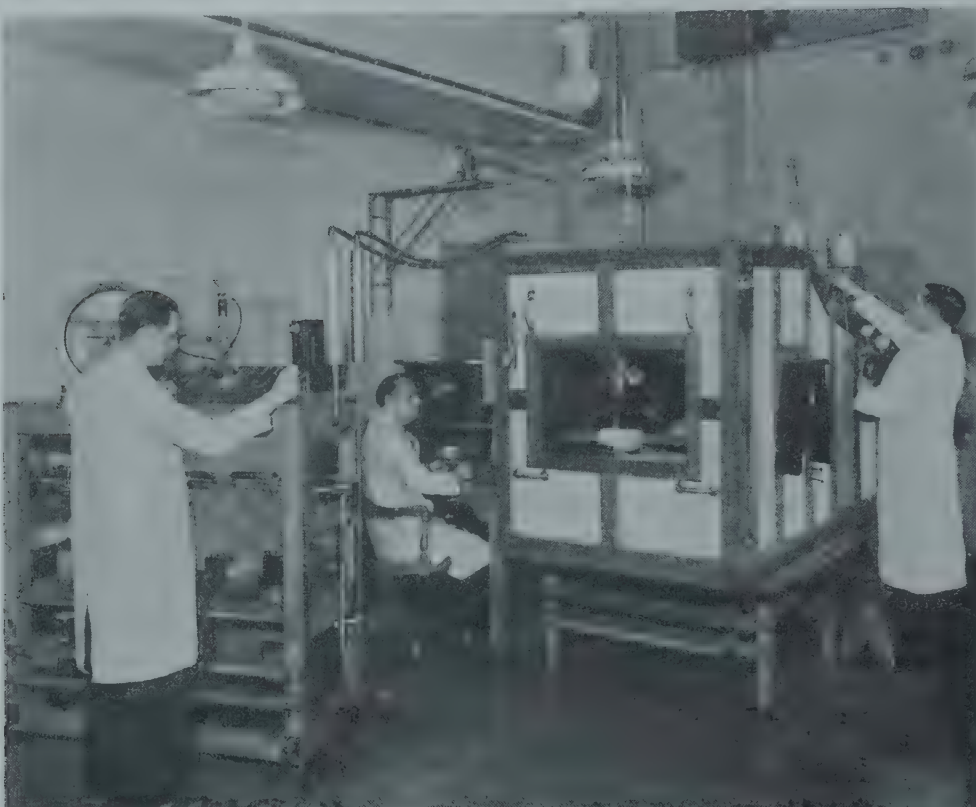

Fig. 6. The respiration calorimeter now in use at the Russell Sage Institute of Pathology. Such an apparatus permits both measurement of the gaseous exchange of the subject and direct determination of the heat which he gives off simultaneously. (Courtesy of Dr. E. F. DuBois.)

The measurements were brought to a very high order of precision; and upon averaging the results of a large number of such experiments it was found that the energy metabolism computed from the data of the respiratory exchange and that measured directly as heat (or as heat plus external muscular work) agreed within a small fraction of one per cent. This finding resulted in general acceptance of the view that energy metabolism may be measured either by direct calorimetry (the man living in a calorim-

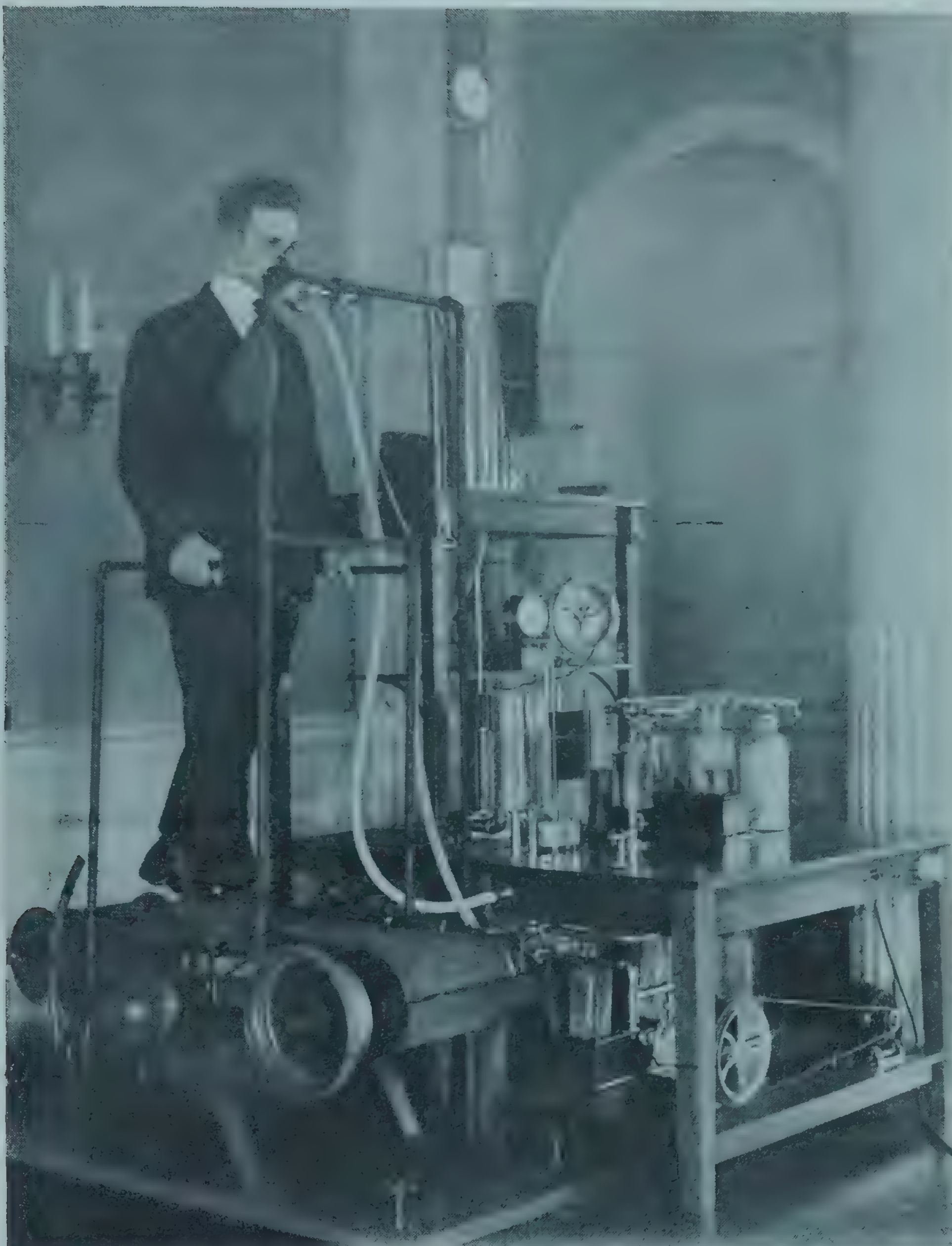

Fig. 7. Apparatus for the study of energy metabolism in walking. In this and in the type of apparatus shown in Fig. 8, the heat production is not measured directly, but the energy metabolism is computed from observations on the respiration, usually of the amount of oxygen consumed. The external muscular work which the subject here performs in walking is measured mechanically. (Courtesy of Dr. F. G. Benedict.)

eter) or by the "indirect calorimetry" of computation from the chemically determined data of the respiratory exchange.

As a further development justified by this finding, there have also been devised several forms of simplified respiration apparatus which while measuring the energy metabolism do so without the need of such elaborate procedures. Thus it has now become practicable to measure the rate of energy metabolism of students in the classroom, patients in the clinic, and representatives of different races as encountered by field anthropologists in various parts of the world. These recently developed outfits, so much more portable and less expensive than those previously available, are also adaptable to the measurement of the energy metabolism of people of widely varied ages and occupations. Hence the somewhat wide-ranging discussions of this and the following chapter can be based almost entirely upon quantitative measurements of actual cases, and usually of many cases of a kind.

Basal Energy Metabolism

The basal energy metabolism (or basal metabolic rate) is a term often applied to the rate of expenditure of energy by a person awake, lying still, at a comfortable temperature, and who has taken little if any food during the past twelve or fourteen hours so that little digestion or absorption of food material is taking place at the time of observation (i.e., in the "post-absorptive" state). This is often measured as a step in diagnosis in modern medicine.

In healthy grown people this basal energy metabolism averages just about one Calorie per kilogram of body weight per hour. This is supposedly the minimal rate of expenditure of the normal man or woman when awake. During sleep the energy output is less, but when sitting erect it is more, while standing involves a still further expenditure of energy. A normal man, therefore, however sedentary he may be, is almost sure to expend in the course of the 24-hour day somewhat more than 24 times his *basal* hourly number of calories.

Moreover in any case the basal rate could be maintained throughout the day only by fasting. Eating is always followed by an increase in the rate of heat production, the extent of the increase depending upon both the character and the amount of food eaten, as explained below.

For a very full and expert account of the measurement and interpretation of the basal metabolism with special attention to its medical aspects, the reader is referred to DuBois' *Basal Metabolism in Health and Disease;* and for a concise but liberally illustrated account, to Taylor, MacLeod, and Rose's *Foundations of Nutrition.* With such authoritative discussions so conveniently available, we

Fig. 8. Measurement, by means of a portable respiration apparatus, of the energy expended by a child washing dishes. (From *Foundations of Nutrition*, 5th Ed. by Taylor, MacLeod, and Rose. The Macmillan Company, 1956. Courtesy of the Nutrition Laboratory, Teachers College, Columbia University.)

here need merely mention any of the factors affecting the basal metabolism which are not themselves essentially nutritional, and we do not enter at all upon the question of pathological conditions.

Benedict has concluded that the basal metabolism of an individual may be considered as quantitatively determined by: (1) the total mass of active protoplasmic tissue; and (2) the total stimulus to cellular activity existing at the time the measurement of the metabolism was made. Age, under such a generalization, becomes

one of the factors causing variations in the stimulus to cellular activity.

The difference between boys and girls, in their basal energy metabolism per unit of weight or of surface, is small in the early years but considerable in their teens; after which the difference diminishes to something like 6 to 10 per cent as between women and men, the latter having the higher rate.

Although loss of heat from the surface of the body is usually rather an end-result than a cause of energy metabolism, yet measurement seemed some years ago to have established empirically that energy metabolism is quantitatively more nearly proportional to body surface than to body weight. Much use has been made of the "surface area relationship" and some authorities treat it as more systematic to express measurements of energy metabolism in terms of Calories per square meter of body surface, than per kilogram of body weight. However, as among normal grown people the ratios between their weights and the ratios between their surfaces are not very different; and any comparison of children with adults requires consideration of the age factor anyway.

What Determines the Rate of Energy Metabolism in a Given Normal Individual at Rest?

While there is a never-ceasing exchange or transformation or metabolism of energy in every living body, the *rate* of this energy metabolism is not constant. It differs between individuals, and in the same individual from time to time.

There is as yet no neat, simple, comprehensive answer to the question, what determines the rate of energy metabolism; but several factors have been studied quantitatively, so that we have well established information as to which are of major, and which of relatively minor, influence.

Thus to speak of two everyday, voluntary factors we may say that for all ordinary conditions the amount of exercise that one takes has more influence in determining the rate of energy metabolism than does the amount of food one takes. A healthy person living with a minimum of muscular activity and eating enough food for maintenance may be metabolizing, say, 1600 to 2000 Calories per 24 hours. This rate of energy metabolism per day can easily

be increased 100 per cent by exercise, while to double the food intake will not increase the 24-hour energy metabolism by more than about 10 or 15 per cent.

But while the food intake is not a major influence in determining the rate of energy exchange in the body, still it has a measurable effect; and it is not the same for the different groups of foodstuffs, nor proportional to their fuel values. In other words food intake does act appreciably to increase the rate of energy metabolism, and this "dynamic" action is "specifically" greater for some of the organic foodstuffs than for others.

Specific dynamic action of the foodstuffs. In the quantitative study of this relationship, by Rubner and by Lusk independently, it was found that when enough food calories for maintenance were fed, in the form of a single foodstuff at a time, the 24-hour metabolism was increased over that of fasting: 6 to 7 per cent by carbohydrate; 4 to 14 per cent by fat; and 30 to 40 per cent by protein. Another way of expressing these same experimental observations is to say that, when each is fed separately, less than one-tenth of the energy value of the carbohydrate of the food, probably about one-tenth of the energy value of the fat, and about one-third of the energy value of the protein spends itself in its specific dynamic effect of increasing the rate of energy metabolism of the body as a whole and for the 24-hour day as a whole. The greater production of heat when protein is largely used as fuel may be a source of comfort when one is exposed to severe cold, or of discomfort in hot weather; but usually is not of importance, because protein constitutes only about a tenth of the food fuel of a normally balanced diet. The exceptionally accurate measurements of Atwater and Benedict showed only 9 per cent of the total food calories expended in the "dynamic action" of the body's direct response to the intake of a *mixed diet;* and Glickman, Mitchell, Lambert, and Keeton (1948) comparing different foods found the specific dynamic action in man to vary between relatively narrow limits (10 to 17 per cent of the total calories consumed).

The influence of the habitual level of food intake. Aside from the immediate specific dynamic effects of the foodstuffs, to what extent does the habitual general level of intake of food calories influence the habitual rate of energy metabolism?

Benedict and his coworkers, studying a group of 12 healthy

young men who voluntarily accepted much reduced rations during the First World War, found that when such undernutrition had reduced the body weight by 12 per cent it had reduced the rate of energy metabolism of the body at rest by 18 per cent. Whether this was an advantageous economy is doubtful. The men remained healthy and able to do their accustomed work, but there appeared to be some lowering of spontaneous vitality.

There are also well authenticated cases of underweight with relatively high energy metabolism which are interpretable in terms of simple absence of adipose tissue and consequent higher percentage of metabolically active lean tissue in the body, as in the lean school children found by Blunt to have rates of energy metabolism per kilogram of body weight from 16 to 24 per cent higher than children of average fatness. That in this case the measured difference in metabolic rate seems somewhat larger than the probable difference in body composition would account for, is easily explainable by the probability of higher muscular tone and perhaps greater thyroid activity in the thinner children. We shall return to the discussion of the thyroid in the Chapter on iodine.

Talbot, also, has shown that undernutrition may result in either an increase or a decrease of the basal metabolic rate, according to circumstances.

Regulation of Body Temperature

As warm-blooded animals we have evolved life processes which depend upon the maintenance of a fairly constant body temperature, and this is above that of our ordinary surroundings. To what extent, then, is the energy aspect of our metabolism a *direct* expenditure for the mere purpose of keeping the body warm? Certainly much less than is often supposed.

When we are comfortably clothed and housed, our body temperature is maintained, chiefly or wholly, by the heat which is produced as a by-product of the work which the life processes involve anyway. And the heat-regulating center in the brain, acting through the nervous and circulatory systems, is able to conserve this resource by constricting the arterioles in the skin and thus diminishing the heat loss from the surface. This is called *physical regulation,* while an increase of oxidation (burning of fuel foodstuffs) for

the direct purpose of producing heat as such to keep up body temperature is called its *chemical regulation.*

For most of us in ordinary daily life, our physical regulation suffices. Only at about the point at which we feel uncomfortably chilly, or at which shivering begins, is the chemical regulation (burning merely for heat) called into play. In fact it appears significant of the body's habitual dependence upon physical regulation that when increased oxidation is needed to maintain temperature the mechanism of muscle activity is still employed, namely, shivering as an involuntary form of muscular work whose function is merely to increase heat production.

The fact that physical regulation very nearly suffices for most of us during most of the time does not mean that the burning of foodstuffs for heat remains at complete zero, for anyone. And such use of food energy value for body heat may be a larger factor in children whose muscles are not yet fully developed, and in the aged whose muscle tone is declining, than in robust young adults. Extreme thinness also may so increase the loss of heat from the body surface as to increase the calorie requirement.

Here as elsewhere the study of nutrition calls for a judicially balanced habit of thought. Need of heat as such for the maintenance of body temperature may at some times and for some people be a real factor in the energy requirement; but the body is not a heat engine, it usually gets enough heat in the course of doing its work, and one should not be misled by the fact that for convenience we count energy values in terms of calories.

Energy Values of Foods in Relation to the Metabolism of Energy in the Body

We saw in the last chapter that carbohydrates, fats, and the nonnitrogenous cleavage products of proteins all serve as fuel in the body. We know also that, throughout a very wide range (though not quite to an unlimited extent), the body can use these different fuel foodstuffs interchangeably in meeting its energy needs. And we have seen also how, though the body is not a heat engine, yet the Calorie serves as a convenient unit for expression and comparison of food energy values and the body's energy requirements.

The energy values of many pure foodstuffs have been deter-

mined by burning weighed specimens in compressed oxygen in calorimeters so arranged as to permit the energy liberated to be very accurately measured as heat (see Fig. 9). Thus one gram of

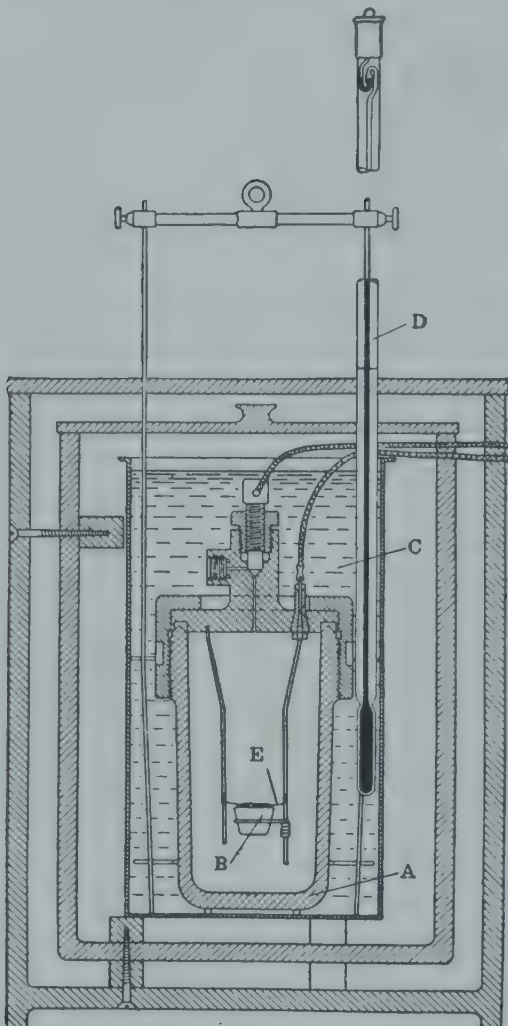

Fig. 9. The Atwater bomb calorimeter for determining the energy values (heats of combustion) of foods. It consists essentially of a heavy steel bomb, A, with a platinum or gold-plated copper lining and a cover held tightly in place by means of a strong screw collar. A weighed amount of sample is placed in a small platinum cup, B, the bomb is then charged with oxygen to a pressure of at least 20 atmospheres, closed, and immersed in a weighed amount of water, C. The water is constantly stirred and its temperature determined at intervals by means of an extremely accurate and sensitive thermometer, D. The sample is ignited by means of an electric fuse, E, and, on account of the large amount of oxygen present, undergoes rapid and complete combustion. The heat liberated is communicated to the water in which the bomb is immersed, and the resulting rise in temperature is accurately determined. After appropriate corrections have been made for loss of heat by radiation, heat arising from accessory oxidations (the oxidation of the iron wire of the fuse, etc.), the number of Calories arising from the combustion of the sample is computed from the rise in temperature of the water surrounding the bomb and the heat capacity of the apparatus.

pure dry starch yields 4.22 Calories, one gram of pure cane sugar, 3.96 Calories.

It is clear that the amount of energy which the body may derive from food will depend on the total heat of combustion as determined by the amounts and kinds of foodstuffs which it contains.

modified, first, by the degree to which these foodstuffs are digested and absorbed, and, second, by the completeness with which they are oxidized in the body. Normally, combustion of carbohydrates and fats in the body is essentially complete, while, for each gram of protein, incompletely oxidized end-products equivalent to about 1.25 Calories are excreted through the kidneys. In estimating the physiologic energy value of proteins, therefore, 1.25 Calories per gram is deducted from the energy value as determined by bomb calorimetry.

The way in which such an estimate of physiologic energy value may be made is illustrated, for whole wheat and patent flour, in Table 3, adapted from Merrill and Watt (1948).

TABLE 3. *Energy Value of Wheat Flours of Different Levels of Extraction Determined from Human Digestibility Studies and Composition Data*

Type of flour	*Percentage composition gm./100 gm.*	*Coefficient of digestibility %*	*Energy value of available nutrient Cal./gm.*	*Available energy Cal./100 gm.*	*"Physiological energy factor" to be applied to ingested nutrient Cal./gm.*
Wheat, whole					
Protein (N × 5.83)	12.94	79	4.55	46.5	3.59
Fat	1.90	90	9.30	15.9	8.37
Carbohydrate	71.46	90	4.20	270.1	3.78
Total caloric value				332.5	
Wheat, patent flour					
Protein (N × 5.7)	11.57	89	4.55	46.9	4.05
Fat	1.18	90	9.30	9.9	8.37
Carbohydrate	74.75	98	4.20	307.7	4.12
Total caloric value				364.5	

From whole wheat flour, the equivalent of $12.94 \times .79 = 10.22$ grams of protein (as digestion products) was available to the body for oxidation from every 100 grams of whole wheat flour eaten. Correspondingly, from white flour, the amount of protein digestion products reaching the body tissues was $11.57 \times .89 = 10.30$ grams. Since the mixed proteins of wheat show an energy value of 5.8 Calories per gram in the bomb calorimeter, their digestion products are presumed to yield $5.8 - 1.25 = 4.55$ Calories per gram in metabolism; so that, allowing for loss in digestion

and for incompleteness of body oxidation, the computed available energy from protein in 100 grams of whole wheat is $10.22 \times 4.55 = 46.5$ Calories, and from white flour, $10.30 \times 4.55 = 46.9$.

Taking 9.3 Calories per gram as the heat of combustion of the fats of wheat, we obtain correspondingly

from 100 grams of whole wheat flour $1.90 \times .90 \times 9.3 = 15.9$ Calories
from 100 grams of white flour $1.18 \times .90 \times 9.3 = 9.9$ Calories.

Calculating the carbohydrates as starch, which, we have seen, has a heat of combustion of 4.2 Calories per gram, the energy available from the carbohydrates of whole wheat flour would be $71.46 \times .90 \times 4.2 = 270.1$ Calories per 100 grams; while, from white flour, $74.75 \times .98 \times 4.2 = 307.7$ Calories per 100 grams would be available.

The product obtained by multiplying the coefficient of digestibility by the energy value per gram of available nutrient is known as the *specific* physiological energy factor of that nutrient in that particular food (or group of foods).

In 1899, Atwater brought together what was known regarding the heats of oxidation and digestibility of nutrients in various classes of foods with what was known of the relative prominence of these classes of foods in the normal American dietary, and concluded that, for such an *average mixed diet* of people in this country, the *total physiological fuel value* could be calculated as the *sum* of

carbohydrate intake (grams) $\times$ 4 Calories per gram;
fat intake (grams) $\times$ 9 Calories per gram;
protein intake (grams) $\times$ 4 Calories per gram.

The factors, 4, 9, and 4, for carbohydrate, fat, and protein are sometimes known as the Atwater factors or as the *general physiological energy factors*, applying to a normal mixed diet, in contrast to the *more specific physiological energy factors*, applying to individual foods or food groups.

For nearly half a century, these general Atwater factors formed the basis of calculations of food energy values in this country, until international problems of food allocation on a caloric basis during and following World War II focussed attention sharply on the fact that to apply these general factors to dietaries consisting much more largely of unrefined foods of plant origin than the American

average, was substantially to overestimate the available calories. The matter of more specific physiological energy factors was therefore reinvestigated and current tables of energy value, such as Table 46 in the Appendix and those of the extensive *Agriculture Handbook No. 8* of the U.S. Department of Agriculture, are based upon the use of these "more specific" factors.

It may be emphasized again that as applied to American and West European dietary data the newer factors yield only slightly different results from those of the Atwater factors. And one may, without serious misapprehension, use the convenient general factors, 4, 9, and 4, for such calculations as are called for in some of the Exercises at the end of this chapter.

Hundred-Calorie Portions

Another way of dealing with the fuel value of foods is to treat the amount of each food which furnishes 100 Calories as a Standard Portion.

100-Calorie portions of some typical articles of food weigh as follows:

Butter (nearly pure fat), about 1⁄2 ounce
Potato chips, 3⁄5 ounce (8–10 large pieces)
Peanut butter, 3⁄5 ounce (scant tablespoon)
Cheese, store, 4⁄5 ounce (about 1 inch cube)
Sugar, about 1 ounce
Any dry cereal, or flour, or meal, about 1 ounce
Dry beans, 1 ounce
Bread, about 1 1⁄3 ounces (about 1 2⁄3 average slices)
Prunes, dry, whole, 1 1⁄3 ounces (four average)
Lean meat, 2 ounces uncooked
Lima beans, shelled, 3 ounces (about 1⁄2 cup)
Peas, shelled, 3 1⁄2 ounces (3⁄4 cup)
Corn, cut, 3 1⁄2 ounces (1⁄2 cup)
Cottage cheese, 3 1⁄2 ounces (5 tablespoons)
Milk, about 5 ounces (2⁄3 glass)
Potato, 5 1⁄3 ounces (one medium)
Banana, 5 1⁄3 ounces (one average)
Apple, 6 ounces (one large)

String beans, 8½ ounces (2⅓ cups, cut up)
Orange, 9–10 ounces (one large or two small)
Lettuce, about 20 ounces

Large numbers of other examples, including many of cooked foods and "made dishes," may be found in *Rose's Laboratory Handbook for Dietetics.*

Familiarity with 100–Calorie portions continues to be found helpful to the gaining of a good grasp of the relative energy (calorie) values of different types of food. Hence it holds an honored place in the learning of food values, even though, both in institutional dietetics and in everyday home practice, foods are generally served either in 100–gram portions or in other conventional "standard" servings. The general food composition Table 46 at the back of this book is in terms of nutrients per 100 grams of edible food.

EXERCISES

1. (*a*) How many Calories did each of your recorded dietaries (daily food intakes) furnish?

(*b*) What was the percentage distribution of each day's total Calories, as between protein, fat, and carbohydrate?

(The use of *Rose's Laboratory Handbook for Dietetics* may greatly facilitate these calculations.)

2. Choose about forty foods[1] and (*a*) compute for each the percentage distribution of its Calories as between protein, fat, and carbohydrate, (*b*) arrange them in three lists in the order of the relative prominence of protein, fat, and carbohydrate, respectively (as thus computed with reference to distribution of the calories).

3. What is the total calorie value for each of these foods, per 100 grams of edible portion?

4. Consulting tables of the average percentage of waste in various foods as purchased (A.P.), prepare a table showing the quantity of each of the forty foods you have selected which you would have to purchase in order to obtain 100 grams of edible portion (E.P.). What would each 100 grams of edible portion cost? Save this information for future reference.

[1] This exercise and the similar ones suggested at the ends of some of the subsequent chapters are intended to develop familiarity with the relative values of different foods as sources of different nutritive factors. It is suggested that your selection of foods include some from each of the eleven groups shown in Chapter 19.

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5

HOW TO MEET THE ENERGY NEED AND HAVE THE BODY WEIGHT YOU WANT

As explained in the preceding chapter, we and other living things "trade" in energy. It is chiefly because we see "expenditures" of energy, as in motion or in the giving off of heat to its surroundings, that we consider an object to be alive. Every living thing, then, is always "spending" energy, or, in more precisely scientific terms, is engaged in processes which involve transformations of energy. The total energy intake required to meet all these expenditures we commonly speak of as the energy need or energy requirement of the body. Having sketched the scientific foundations of this subject in Chapter 4, we now take up its everyday functioning.

Activity, age, and size are the outstanding factors in determining the amount of energy needed by a healthy person under ordinary conditions of life.

Mental and Muscular Activity as Factors in Energy Metabolism

Soon after the satisfactory development of their respiration calorimeter (noted in Chapter 4), Atwater and Benedict arranged to have 22 college students (separately) take mid-year examinations in this apparatus, so that the energy metabolized while performing this mental work could be measured and compared with that shown by the same person for a parallel period at the same time of day, in the same physical posture and surroundings, but with no mental work to do. There was no marked or constant difference in the results. Some students showed a slightly higher, and some a slightly lower, energy metabolism while taking the examination than in a period of equal length with parallel physical condi-

tions without mental demand. If the mental work increased energy metabolism in the brain, the quantitative effect was so small as to be lost in the unavoidable fluctuations that occurred in the muscles. Even the brainiest person has many-fold more pounds of muscle than of brain, and spends many hundreds of Calories per day in muscular tension or tone. That some students spent more energy during their examination was probably mainly because their muscles as well as their minds were more tense during the ordeal than on the day of rest. And that some other students showed decreased energy expenditure during the examination period was probably because they were so well prepared and self-disciplined that the more they concentrated their minds upon the examination questions the more completely their muscles relaxed.

The factor of muscular tension was probably more perfectly controlled in the later experiments of Dr. and Mrs. Benedict. In repeated experiments the Benedicts were able to demonstrate an increase of energy metabolism during periods of mental work. But the difference was so slight that they decided to make clear its smallness by reporting that the extra energy involved in an hour of mental work was no more than is furnished by half a peanut.

Thus the contrast between mental and muscular work is very pronounced, so far as its quantitative effect upon energy metabolism is concerned.

In the healthy adult, muscular activity is usually the largest variable factor in determining the rate of energy expenditure.

The average-sized man who spends about 100 Calories per hour while sitting still will (for the time being) approximately double this rate of expenditure if he simply strolls around the room, or treble it if he walks vigorously.

Moderate use of large muscles may easily involve a greater expenditure of energy than does the most intense use of a set of much smaller muscles. Thus the slowest walking will probably involve a larger output of calories per hour than the fastest typewriting.

Typical findings of energy metabolism per minute in healthy grown people (weighing about 70 kilograms) while differently occupied are shown in Table 4 (adapted from writings of the late Dr. Mary S. Rose and the review of Passmore and Durnin, 1955).

In using such a table it should be remembered that individuals vary widely in the vigor or pace with which they perform the same

TABLE 4. *Approximate Energy Expenditure in Various Activities in an Adult of Average Size*

Activity	*Calories/ minute*	*Activity*	*Calories/ minute*
Sleeping	1.0	Making beds	4.6
Lying at ease	1.4	Scrubbing	4.7
Sitting at ease	1.6	Walking, 3.5 miles/hour	4.8
Office work, sitting	1.6	Gardening, weeding	5.0
Hand sewing	1.8	Archery	5.2
Standing at ease	1.8	Tennis	7.1
Office work, standing	1.8	Horseback riding, trot	8.0
Typing rapidly	2.1	Bicycling (depends largely on speed)	8.2
Sweeping	2.4	Walking up and down stairs	8.3*
Light laundry	2.7	Swimming (depends largely on speed)	8.4
Driving automobile	2.8	Gardening, digging	8.6
"Personal necessities" (dressing, undressing, washing, shaving)	3.0	Squash	10.2
Playing with children	3.5	Cross-country running	10.6
Walking, 2.5 miles/hour	3.6	Walking, 5.3 miles/hour	10.8
Cleaning windows	3.7	Mountain climbing	12.0
Taking out, hanging wash	4.0	Sprinting	20.0
Ironing	4.2		

* This figure represents the combined operation of going up and down stairs. It is estimated that it requires about three times as rapid energy expenditure to climb stairs as to descend, and that the total operation of going up and down the average household stairs once involves about 3.0 Calories for a 60 kilogram individual (Passmore and Durnin, 1955).

activities, and that naturally the rate of energy expenditure will vary accordingly. This is illustrated by Table 5, based on the information which has been gathered in a vast number of studies on the energy metabolism of many persons walking, at different rates, on level ground. It is seen, for example, that when a 140-pound man doubles his pace from 2 miles per hour to 4 miles per hour, he increases his rate of energy expenditure by about 80 per cent.

Even at the same rate of performance, the cost of activities will vary somewhat with the individual. In a careful study in which the energy expenditure was measured in 50 persons walking under standard conditions at 3 miles per hour, it was found that age,

sex, and race had no significant effect on the metabolic cost of the work. The body weight, however, had an important effect on the energy expenditure, as shown in Table 5.

TABLE 5. *Relationship Between Energy Expenditure (Calories per Minute) and Speed of Walking and Gross Body Weight* (Passmore and Durnin, 1955)

Speed, miles per hour	*Weight in pounds* 80	100	120	140	160	180	200
2.0	1.9	2.2	2.6	2.9	3.2	3.5	3.8
2.5	2.3	2.7	3.1	3.5	3.8	4.2	4.5
3.0	2.7	3.1	3.6	4.0	4.4	4.8	5.3
3.5	3.1	3.6	4.2	4.6	5.0	5.4	6.1
4.0	3.5	4.1	4.7	5.2	5.8	6.4	7.0

Too great precision should not therefore be expected from such a table as that giving the energy cost of various activities. In using it, one who is much above or below the average size of 65 or 70 kilograms will wish to make some allowance for this difference in body weight. It is conventional for such purposes to assume that the energy cost of the activity varies directly with the body weight, but one should realize that the proportionality is not exact. For instance, the average 160 pound man does not use exactly twice as much energy in walking, say at 3 miles per hour, as the average 80 pound individual, nor the 180 pound man one and one-half times as much energy as the 120 pound man (see Table 5). Nor can one assume, because the weight effects on walking are quite well established, that the same effects will apply to other activities. For instance, the fact that the 140 pound individual expends 30 per cent more energy than the 100 pound individual in walking at the rate of 3 miles per hour, does not permit one to assume that he will use 30 per cent more Calories in typing; since in the former case the actual moving of the body weight is an important part of the net cost of performing the work, while in the case of typing only a few relatively small muscles are called into play, and the body weight of the individual should have little effect on the extra energy which typing requires over sitting still.

The energy costs of various agricultural, military, and industrial activities have been studied, under the stimulus of wartime food

shortages. A detailed summary of the findings has recently been published by Passmore and Durnin (1955). The same authors regard as "sensible" Christensen's definitions of different grades of work:

unduly heavy, energy expenditure over	12.5 Calories/minute
very heavy	10.0
heavy	7.5
moderate	5.0
light	2.5

They emphasize that "the definitions only apply to rates of work which are carried on continuously for periods of a few minutes" and that "periods of heavy work must be punctuated by rest pauses" so that the definitions do not apply to average daily rates of work. The "endurance limit" or average rate of energy expenditure which a normal man can maintain for eight hours a day, day after day, without cumulative evidence of fatigue, is considered to be about 5 Calories per minute.

Total Energy Allowances for Adult Maintenance

It used to be customary to cite energy allowances per day for persons employed in different occupations. But such estimates have come to have less significance as the amount of leisure time of the average worker has increased until now he may have as many hours to spend in recreational pursuits as in his chief occupation. Thus a "sedentary" clerk who enjoys vigorous outdoor sports, gardening, and hiking in his spare time may thereby increase his total weekly energy output to that of the miner or factory worker whose work is classified as "heavy labor" but who spends most of his leisure watching television or reading.

By the use of a record of the amounts of time spent in different sorts of activities and data such as those in Table 4, one may estimate the daily energy expenditure, as in the following imaginary example of an office worker of average size.

The Recommended Allowances of the National Research Council (the "yardstick" explained in Chapter 1) refer to the socalled "standard" man weighing 65 kilograms (143 pounds) and the

TABLE 6. *Estimation of Total Energy Expenditure from Time Spent in Various Activities*

Activity	Time spent Hours	Minutes	Energy expenditure Calories/minute	Total Calories
Sleeping	8		1.0	480
"Personal necessities" (dressing, undressing, washing, shaving)		35	3.0	105
Driving to and from work		40	2.8	112
Office work	8		1.8	864
Light sedentary activities, e.g., eating, reading, television viewing	3	20	1.6	320
Tennis	1	40	7.1	710
Walking, 3 miles per hour		30	4.2	126
Playing with child	1	15	3.5	262
			Total	2979

"standard" woman of weight 55 kilograms (121 pounds), who live in a moderate climate and are "fairly active physically, being neither sedentary nor engaged in hard physical labor as a major occupation." For such individuals the total caloric intakes recommended at several ages are as follows:

Recommended Caloric Allowances for Fairly Active Adults

Age	Man (65 kilograms, 143 pounds)	Woman (55 kilograms, 121 pounds)
25	3200 Calories/day	2300 Calories/day
45	2900 " "	2100 " "
65	2600 " "	1800 " "

In using these recommendations, it is important to keep clearly in mind the degree of physical activity they are intended to support. It should be remembered that "sedentary" and "fairly active" as they appear in the description of the standard man or woman refer to the muscles and not to the mind. Yet even in the writings of nutritionists, busy men and women working long hours and carrying heavy responsibilities are apt to be considered "fairly ac-

tive" whereas they are in fact "sedentary" in the terms of the Recommended Allowances. As illustrating what is considered a "fair" degree of physical activity, the Food and Nutrition Board comments:

The man could be employed in light industrial work; he could be a delivery man, a painter, an outdoor salesman, or a farmer except in the periods of heaviest farm work. The woman could be employed at bench work in a factory; she could be a shop saleswoman, or an active home-maker and mother. Both man and woman are presumed to engage in a moderate amount of outdoor recreation and to lead a vigorous healthy life.

Adjustments for differences in body size. For men and women differing from the standard body sizes, the caloric allowance may be calculated from the formulas:

$$\text{Calories for men} = 152 \ (\text{weight in kilograms})^{.73}$$
$$\text{Calories for women} = 123.4 \ (\text{weight in kilograms})^{.73}$$

or estimated from the following table which gives the percentage of the standard caloric allowance corresponding to different body weights.

Adjustment of Caloric Allowance for Deviations of Body Weight from that of Standard Man and Woman

Weight in pounds *Men*	*Women*	*Per cent of standard allowance*
105	90	80
124	104	90
143	121	100
163	135	110
183	156	120

Adjustments for differences in external temperature. Recognizing the fact that colder climates call for somewhat increased energy allowances and warmer-than-normal climates for a somewhat lower energy intake, the Recommendations define a moderate climate as one with mean *annual* temperature of 10° C. (about that observed in Boston, Cleveland, Chicago, Omaha, Denver, Detroit, Salt Lake City, and Santa Fe). They suggest that for every increase of 10° C. in the mean external temperature the energy allowance be reduced 5 per cent below the standard

uggested in the table, and that a corresponding increase in energy llowance be made for each decrease of 10°C. in the mean external emperature.

In practical terms this would mean that such places as Minneapolis nd Burlington, Vermont would have annual calorie allowances about 2 per cent higher than standard; while a reduction of 5 per cent would be appropriate for most parts of the Southern and Southwestern states and Southern California, and a reduction of about 8 per cent would be proper for Puerto Rico.

Where precise estimates are desired on a season-to-season basis, similar allowances may be made for the mean external temperature at the different times of year.

The explanation which accompanies the Recommended Allowances also explains that "all adjustments for climate presuppose an ordinary amount of actual exposure to the climate. For persons spending most of their time out of doors, these adjustments may be insufficient, particularly during winter in the Northern and Central States."

The text accompanying the "yardstick" table comments, regarding the calorie recommendations that "for the urban 'white collar' worker they are probably excessive." It is moreover frank in recognizing "the fallibilities of the allowances as applied to individuals" and emphasizes that *"the proper caloric allowance for an individual is that which over an extended period will maintain body weight . . . at the level most conducive to well-being."*

Food Calories and the Control of Body Weight

The past decade or two has seen a growing concern at the prevalence of overweight among American adults and at the evidence that this overweight is strikingly associated with a greater incidence of degenerative diseases and an increased deathrate. To this fault in our national eating habits is attributed the fact that life expectancy at age 40 is less in the United States than in 16 other countries (Jolliffe, 1953). It has long been recognized by life insurance companies that persons who are grossly overweight are notoriously poor risks. And what has been regarded, on the basis of insurance statistics, as the "ideal weight" has undergone a downward revision in recent years until now it is commonly set at the average weight for height at age 25 (see Table 7).

TABLE 7. *"Ideal Weights" for Men and Women of Ages 25 and Over*°
(proposed by the Metropolitan Life Insurance Company)

Height (with shoes on)		*Men*			*Women*		
feet	*inches*	*Small frame pounds*	*Medium frame pounds*	*Large frame pounds*	*Small frame pounds*	*Medium frame pounds*	*Large frame pounds*
4	11				104–111	110–118	117–127
5	0				105–113	112–120	119–129
5	1				107–115	114–122	121–131
5	2	116–125	124–133	131–142	110–118	117–125	124–135
5	3	119–128	127–136	133–144	113–121	120–128	127–138
5	4	122–132	130–140	137–149	116–125	124–132	131–142
5	5	126–136	134–144	141–153	119–128	127–135	133–147
5	6	129–139	137–147	145–157	123–132	130–140	138–150
5	7	133–143	141–151	149–162	126–136	134–144	142–154
5	8	136–147	145–156	153–166	129–139	137–147	145–158
5	9	140–151	149–160	157–170	133–143	141–151	149–162
5	10	144–155	153–164	161–175	136–147	145–155	152–166
5	11	148–159	157–168	165–180	139–150	148–158	155–169
6	0	152–164	161–173	169–185			
6	1	157–169	166–178	174–190			
6	2	163–175	171–184	179–196			
6	3	168–180	176–189	184–202			

° The weights include ordinary indoor clothing, and the heights provide for shoes with one inch heels. The same table will apply satisfactorily for nude heights and weights.

The prevalence of *overweight*, defined as a deviation of more than 10 per cent from the ideal weight of the individual, has been estimated at one-fifth to one-fourth of the population of the United States above age 30 (and Sebrell states that among older women 60 per cent may be overweight). About one-third of the overweight adults, or some 5 million Americans, fall into the classification of *obesity* or pathological overweight, which (in lack of direct estimation of body fat) has been defined as more than 20 per cent above the ideal weight for height. Compared with the incidence of all the known dietary deficiency diseases recognized in this country, this incidence of dangerous overweight is enormous. Obesity is thus often characterized as the most common form of malnutrition in the United States, and the most serious in terms of the total years of life sacrificed.

For the evidence of life insurance statistics (see, for example, Armstrong *et al.*, 1951) is overwhelming that the deathrate is strikingly greater in overweight groups than in groups of normal or ideal body weight. And overweight seems also to be associated with greater incidence of such conditions as high blood pressure, heart disease, cirrhosis of the liver, diabetes, and gallbladder trouble. As Sebrell (1953) expresses it, "it may not cause the conditions, but it is a dangerous and undesirable concomitant."

It should be emphasized that there is reason to believe that up to the age of 20 or 25 there may be some advantage in a moderate degree of overweight (up to 10 per cent above the "ideal" as defined earlier). On the other hand, a greater degree of overweight was found by Dublin and Marks to be even more hazardous in the 20 to 30 age range than later in life.

It is unquestionably far better to avoid excessive overweight than to try to correct it after it has developed. Yet those already overweight may derive encouragement from a study (Dublin and Marks, 1951) of the subsequent history of a group of individuals who were initially overweight but who later reduced their body weight: by so doing the mortality rate was decreased very markedly from that predictable from their initial weight (although, to be sure, it remained somewhat above the mortality rate of those who were initially of normal weight).

Returning to the question of what constitutes the ideal weight for any individual, attention is called to the fact that Table 7 makes allowance for the type of frame or body build, since it is of course obvious that the person with a broad, stocky frame should weigh more than a slenderly built individual of the same height. Common sense would also suggest that an athlete with exceptionally well developed musculature can weigh much more without being "overweight" than an individual of the same height with less muscle tissue. On the other hand, there are cases in which the body weight is excessive because of a disturbance in the water balance. Overweight of this sort may be medically undesirable, but it will usually yield to treatment other than caloric restriction. Those who are concerned with regulating their body weight through diet will, however, do well to keep in mind that shifts in body water balance may sometimes obscure a real gain or loss of body fat.

It is over-fatness, not overweight *per se*, which is the health prob-

lem with which we are here concerned. In very exact studies, th actual amount of body fat has been determined by measuremen of the specific gravity of the body and the total body water. Studie have also been made of the amount of subcutaneous fat in variou portions of the body, as estimated from the thickness of a fold o skin measured by calipers. From a comparison of such skinfol measurements with actual determinations of body fat, equation have been developed which make it possible to translate skinfol measurements into total "nonessential" body fat, where such in formation is required in scientific studies of starvation, obesity, an related subjects. And, in popular writing on weight control, an ex pression, "the educated pinch," has come into use as a dependabl indication of the need to reduce body weight. For that, the Harvar group suggests gathering up a fat fold under the chin, or on th abdomen, chest, arms, or calf of the leg—if the fold is more tha an inch thick, they suggest it is time to give thought to weigh control.

We have seen that surplus calories of ingested food, whethe taken in the form of protein, fat, or carbohydrate, tend to ac cumulate in the form of body fat. And over-fatness always mean that the intake of food calories has been out of proportion to th expenditure of energy *by the person concerned.*

What makes some people eat out of proportion to their energy needs is a problem to which there seems to be no one simple an swer, though a number of physiological and psychological explanations have been advanced to explain certain cases of overeating. No doubt any fairly large and representative group of overweight persons would include some individuals for whom a distortion or disturbance of normal appetite can be explained on purely physiological or endocrine grounds; some who are extraordinarily efficient in their utilization of food energy, so that they "fatten" on a food intake which just suffices for maintenance in other individuals of the same height and activity (probably predominantly a hereditary characteristic, as in certain strains of livestock which are prized for this property); some whose activity has been sharply restricted after a vigorous, energetic life (and whose eating habits have not adapted to the change); still others for whom eating is a sort of hobby in which they overindulge; and many more who seek in overeating a relief from worries, tension, frustration, and boredom,

some becoming addicted to it as others may be to alcohol. In addition, there is evidence from experiments with animals (see, for example, Mickelsen *et al.*, 1955) that potentially normal individuals may be forced into patterns of obesity by distorted diets, in the instance cited, by diets extraordinarily high in fat. An understanding of the cause of the overeating in an individual instance may be helpful in assuring that, once normal body weight has been restored by dietary control, the individual will not then revert to the old practice and regain the lost weight. The failure of many carefully planned and initially successful weight reduction programs to secure permanent results is one discouraging feature of the obesity problem today.

Whatever the cause of the overweight, the fact remains that for the individual the control of body weight is essentially a matter of a proper balance between what is ingested as food and what is oxidized in the energy metabolism. If one tends to become too fat, the remedy is to eat less or to burn more, or both.

To increase basal metabolism by administration of thyroid, thyroxine, or any artificial drug designed to increase oxidation is too dangerous except under strict medical control.

To increase the energy metabolism by muscular exercise is probably beneficial in a fair proportion of cases, with the exception of markedly obese persons, in whom muscular exercise may endanger the heart.

However, as Professor Mary S. Rose used to teach, "the only form of exercise *essential* to the control of body weight is the exercise of the intelligence."

Weight reduction can assuredly be accomplished by dietary measures alone, without resort to exercise.

Suppose that, having determined he is too fat for best health, one proposes to undertake a weight reduction regimen. A first step is to estimate what energy intake should support him at his *ideal* (not his present) weight and customary degree of muscular activity; and from this to *plan for a daily deficit of about 500 Calories* —by restriction of caloric intake, or by increased exercise, or by a combination of both.

A withdrawal from bodily stores of about 500 Calories per day or 3500 Calories per week will normally mean the burning off of about 380 grams of actual fat. And this will mean a reduction of

body weight by about one pound of adipose tissue; for adipose tissue is about $\frac{8}{10}$ to $\frac{9}{10}$ actual fat and about $\frac{1}{10}$ to $\frac{2}{10}$ water. Thus the daily deficit of 500 Calories reduces body weight by about one pound per week, and this is about as rapid a reduction as one should attempt unless under constant medical advice and observation.

One should not be discouraged or confused by short-time fluctuations of body weight. Not only may the body gain or lose a few pounds of water without apparent reason or effect upon health, but also the fluctuations in the body's glycogen or protein stores influence its water content at the same time, each gram of glycogen or protein being usually accompanied by about 3 grams of water. Thus 400 Calories gained or spent in the form of 100 grams of glycogen or protein may quickly change the body weight by about 400 grams, while the gain or loss of this weight of fat tissue would involve about 3200 Calories. The reason for the spectacular weight losses on some very drastic "reducing" (actually starvation) diets is the fact that they result in marked loss of body glycogen and body protein, with accompanying water. The first few days after return to a maintenance level of caloric intake following such a drastic diet are apt to see just as spectacular a gain in weight, as the normal store of glycogen is rebuilt, and water stored with it.

Most essentially normal individuals with a moderate degree of excess weight to lose will find it possible to do so by "counting the calories" and persisting in brisk, regular exercise, not carried to the point of exhaustion. In restricting the energy intake, the scientific attitude does not simply ask, Is this food fattening?, nor even simply, How fattening is it?, but *both*, How does it stand as a source of calories?, and, How important is it as a source of protein and of the needed mineral elements and vitamins? Almost always the desirable degree of reduction of calorie intake can be made among the foods that are not important sources of mineral elements and vitamins, and it is among such foods that the "cutting out" or the "cutting down" should be done. For such persons as we are here considering the best long-term results are apt to come from modifying the food habits in directions that may be permanent.

Persons who are greatly overweight, or for whom the explanation does not appear to lie in simple overeating, will probably do best to have medical advice in outlining a plan for weight reduction.

The types of special diet which have been commended by serious students of the problem are many and diverse, as may be seen from study of the Suggested Readings.

Though it presents a much less common problem in this country than overweight, extreme thinness also is a real hazard. Especially among girls and young women, an important proportion keep themselves thinner than is best for health, happiness, efficiency, and longevity. As the late Professor Rose emphasized, underweight college women commonly regard themselves as well, and then are surprised to find how much better they feel, and how much less subject to fatigue, when they build up their weight to correspond to the life insurance "ideal."

A moderate amount of body fat is a real asset and not simply as stored fuel. Fat deposits in the abdominal cavity serve as packing and support for the kidneys, and doubtless to some extent for other vital organs as well; while a subcutaneous layer of fat tends to protect muscles from bruises, and the body as a whole from the effects of sudden changes in the temperature of its surroundings.

In cases in which either lack of appetite or a subnormal digestive capacity makes the taking and digesting of sufficient food a real problem, attention should be given to such selection of food and arrangement of meals as to stimulate the appetite and avoid overburdening the digestive apparatus, and care should also be taken that there is sufficient outdoor life, and sufficient ventilation indoors, to develop and support a good appetite; that fatigue of any kind or at any time is avoided; that provision is made for complete rest before and after meals; and that the meals contain an abundance of fruits, vegetables, and milk as well as more concentrated foods.

The proper nutrition of an underweight person is only in part the reverse of the proper correction of overweight, since in both cases the calories in the food and the fat in the body while prominent in the problem do not tell the whole story. Such important protective foods as fruit and milk should be fairly prominent in both the fattening and the reducing types of diet.

Energy Needs During Physical Development

Pregnancy and Lactation. It is the judgment of medical men that a desirable weight gain during pregnancy (including the

weight of the infant) is about 20 to 25 pounds for the woman who is initially of about the ideal weight for her height. Women who are underweight will benefit by a greater weight gain than this; while women who enter pregnancy overweight face the difficult prospect of having to provide for increased protein, mineral, and vitamin needs while restricting carefully their caloric intake. The number of calories to be provided for the pregnant woman in addition to the normal allowance thus depends in part on the weight gain which is desirable for the individual in question and in part on the degree to which she maintains her customary physical activities during her pregnancy. The recommendation that the pregnant woman increase her normal (nonpregnant) calorie intake by 400 Calories per day during the last third of pregnancy is thus intended by the Food and Nutrition Board as an approximate suggestion only, the exact assessment in any individual case being a problem for the attending obstetrician.

During lactation, the increased energy need is still greater, though variable of course with the amount of milk being secreted. The National Research Council recommendation is that the nursing mother producing 850 milliliters of milk should add 1000 Calories to her normal allowance.

Allowances for Growing Children. Investigations of young infants regularly show them to give off at least twice as much energy per unit of weight as their mothers do. This is partly explainable on the ground of size and surface. For, as between a baby and a grown person, the ratio of surface to weight is very different, and, as energy metabolism is more nearly proportional to surface than to weight, the baby's larger surface per pound would of itself mean more calories per pound.

Secondly, children soon begin to be muscularly active. Their crying and kicking may add from 25 to 100 per cent to the 24-hour calorie requirement. By the time this stage of their development is over, the run-about stage has begun. Most grown people would find their muscles overworked if they tried to repeat their children's physical activities.

Thirdly, the child's food requirement is further accentuated by the fact that the intake must not only cover the output but provide also for retention by the body of the food substances which become tissue material in the processes of growth.

The following table presents the caloric allowances recommended for infants, children, and adolescents. Though set up in terms of age, a more suitable allowance for the individual who is advanced (or retarded) with respect to his physical development may sometimes be found by referring to the grouping which more accurately describes his height and weight.

TABLE 8. *Recommended Caloric Allowances for Infants, Children, and Adolescents* (Food and Nutrition Board, National Research Council, Revised, 1953)

Age years	*Height cm.*	*in.*	*Weight kg.*	*lb.*	*Calories*
Infants					
1/12–3/12	60	24	6	13	kg. × 120
4/12–9/12	70	28	9	20	kg. × 110
10/12–1	75	30	10	22	kg. × 100
Children					
1–3	87	34	12	27	1200
4–6	109	43	18	40	1600
7–9	129	51	27	59	2000
Boys					
10–12	144	57	35	78	2500
13–15	163	64	49	108	3200
16–20	175	69	63	139	3800
Girls					
10–12	144	57	36	79	2300
13–15	160	63	49	108	2500
16–20	162	64	54	120	2400

Energy Metabolism in Elderly People

Emerson was sixty-three when he wrote with reference to his age, "It is time to take in sail." How shall we translate his poetic expression of physiological experience into terms of energy metabolism?

First of all it should be emphasized that people differ in their reactions to the passage of years. Some are younger at seventy than others are at sixty, and the difference while largely constitutional is also doubtless due in greater measure than previously believed,

or yet generally appreciated, to the internal environment induced and maintained by one's daily choice of food.

When, somewhere in middle or advancing age, the effect of diminishing muscular activity is added to that of the slow decline in basal metabolism, the result is a significant decrease in the number of food calories needed per day. It has been pointed out further (Keys, 1952) that a gradual loss of weight is desirable in later life, since there is inevitable loss of muscle tissue. Thus, the healthy young man who contains about 10 per cent of fat at his "ideal" weight may, if he maintains this same weight into old age, come to contain as much as 22 per cent of body fat. Leanness has come to be considered a natural and desirable physiologic attribute of aging, and obesity is recognized as aggravating many of the disabilities of the elderly. Probably, past seventy, health and vigor can be maintained in women on intakes of 1500 Calories or less, and in men by about 2000 Calories; though this must be expected to vary with the degree to which the elderly have managed to preserve the "characteristics of youth," as evidenced by their musculature and activity.

EXERCISES

1. Compute your Calorie requirement per 24-hour day, from the number of hours you spend in different activities (correcting for your body weight, if significantly different from 65 kilograms, on assumption that energy expenditure is proportional to body weight).

2. Plan a day's dietary to meet your computed Calorie requirement, choosing the foods from among the forty with which you have familiarized yourself in the Exercises of the preceding chapter.

3. How would you change the dietary planned in Exercise 2 to make it a reducing dietary with about 500 Calories less of total energy value?

4. A student 20 years old and 5 ft. 5 in. tall is underweight. Modify the dietary planned in Exercise 2 above so as to build up the body weight of this student. Is the "fattening" diet you have thus planned appetizing? Is it comfortably digested? Is it reasonably economical in cost?

5. How many Calories of food per day would you allow for a family consisting of a service station attendant of 45 (weight 183 pounds); wife of 45 (weight 104 pounds) who does all of the housework; a girl of 15, a boy of 13, and a boy of 11, all these children of average size for their ages and all attending school?

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6

HOW TO MEET THE NEED FOR PROTEIN

Uses of Proteins in the Body

A brief glimpse of the nature and significance of protein was met in Chapter 2 and in the summary (near the end of Chapter 3) of the fate of foodstuffs in the body. We saw that protein (1) may be used in the building or upkeep of body tissues, or (2) may serve as precursors in the formation of certain specific regulatory substances (hormones, enzymes), or (3) may in part be used as body fuel—along with carbohydrate and fat.

The prominence of the proteins as components of body tissues, and their importance to life processes as precursors of hormones and enzymes give them a very fundamental place in the science of nutrition. And these facts together with traditional considerations give protein such *prestige* or *status value* as tends to continue the investment of a large share of the food budget in protein notwithstanding the great importance of several of the more recently discovered factors in food values.

Hence the present chapter has a two-fold importance: to amplify and clarify our understanding of the ways in which the proteins (and their amino acids) serve the nutritional needs and processes of the body; and to consider how much protein should be provided in our normal daily dietaries.

Interpretation of the Nutritive Functions of Proteins in Terms of Their Amino Acids

As we have already seen, the large complex protein molecule is hydrolyzed by digestion to the amino acids of which it was essentially composed.

Every typical protein yields on hydrolysis at least several different kinds of amino acids; and at least twenty kinds of amino acid are now recognized as commonly received by the body from its protein food. The familiar names of these are: alanine, arginine, aspartic acid, cystine, glutamic (glutaminic) acid, glycine (glycocoll), histidine, hydroxyglutamic acid, hydroxyproline, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tryptophan, tyrosine, and valine. The chemical names and structural formulas of these amino acids are given in many textbooks of biochemistry and in Chapter IV of Sherman's *Chemistry of Food and Nutrition.*

It is essentially in the form of amino acids that food proteins are absorbed from the intestinal tract and carried to the tissues where they are used. Indeed, Professor W. C. Rose of the University of Illinois has demonstrated that a suitable mixture of amino acids is a nutritionally satisfactory substitute for protein even in the diet of young, growing experimental animals. Grown men also could be kept, without loss of body protein, for many weeks on a diet in which the protein was replaced by a mixture of purified amino acids.

From the amino acids which the blood distributes, the organs and tissues build (synthesize) the numerous body proteins upon which many aspects of the life process depend. For, not only are the proteins essential components of all protoplasm, and the most abundant constituents of the active tissues: they and their derivatives have other highly significant functions as well. Many of the enzymes and other catalysts which the body makes, it makes either wholly or in part from the digestion products of the food proteins. Moreover, the hemoglobin in the red blood cells, which transports oxygen from the lungs to the tissues where it is needed, is a protein. And, throughout the body, proteins in solution play an essential part in maintaining neutrality and in controlling the distribution and exchanges of the body water.

In addition to their use for the synthesis of proteins, some of the amino acids go into the formation of less complex substances, such as glutathione (which contains the amino acids glycine, cystine, and glutamic acid); and the hormones epinephrine (adrenaline) and thyroxine, which are related to the amino acids phenylalanine and/ or tyrosine.

Secretin, which was mentioned in Chapter 3 as the hormone which serves as the "messenger" from the intestine to the pancreas in digestion, has also been found to be an amino acid derivative. It is classed as a polypeptide, being intermediate in molecular size between such a chemically simple hormone as thyroxine, and, on the other hand, such a typically protein substance as insulin.

The amino acids in excess of those required for the specific functions of the building or upkeep of body proteins or the formation of other nitrogenous substances, are deaminized (lose their amino groups) and the remaining fragments are burned to yield energy or converted into body fat. But, since we know that carbohydrate and fat are efficient fuels to meet the body's energy requirement, this is not to be regarded as a specific function of the dietary protein in the same sense as those functions discussed in the preceding paragraphs. *Upkeep* seems a better word than "repair" to indicate the exchange of material which goes on constantly even in entirely normal (uninjured) tissue. On the other hand, it is partly for reasons of repair that a surgeon may wish the protein content of a diet for his surgical patient to be relatively higher than its fat or carbohydrate content or total calorie value.

Factors Determining the Nutritive Value of Proteins

It has long been recognized that all proteins are not of the same value in nutrition. Thus, in 1872 Voit found that the protein gelatin could not be substituted for meat protein in the diet of dogs without some loss of body protein. Later, Osborne and Mendel, in some of the early work using rats as tools[1] for nutrition research, compared the nutritive effectiveness of a number of purified proteins (Fig. 10). They found, for example, that when the only protein in the diet of young rats is casein the animals are able to grow normally, while if gliadin, one of the proteins of wheat, is given as the sole food protein the animals, although they maintain their

[1] The experimental animal is only a tool or instrument of research when the problems are those of human nutrition; but it may be well to emphasize at this point the fact that the chemistry of the protein metabolism has been studied in considerable detail and found to be in many parts strikingly parallel in human and rat nutrition. Thus the rat, in addition to being a very useful tool, can also function to some degree as a sort of "deputy" for man in the experimental study of proteins in nutrition.

body weight (and stores of protein), grow little or not at all. If, however, zein, *one* of the proteins of corn (maize), is the only protein fed, the animals soon begin to lose weight, and ultimately die. When tryptophan, an amino acid present in zein only in traces—but found in casein and in gliadin (and also in maize proteins other than zein)—is given in addition to zein, rats may be able to maintain their body weight although they cannot grow. But if lysine,

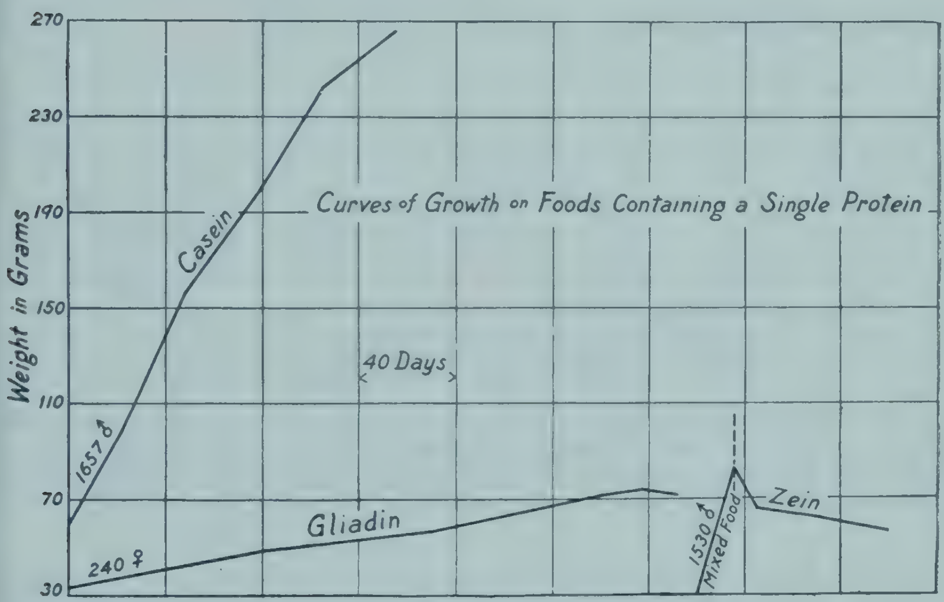

Fig. 10. Effect of the kind of protein in the diet on the rate of growth. Body weight curves of typical rats on diets otherwise similar and adequate but containing in each case only a single protein, casein, gliadin or zein, fed at the same liberal level, 18 per cent of the food mixture. (From the experiments of Osborne and Mendel.)

another amino acid which zein lacks, is further given in addition to the protein zein and the amino acid tryptophan, the rats are enabled to gain weight rapidly (see Fig. 11).

Correspondingly, an explanation of the fact that gliadin as sole protein in the diet suffices for maintenance but cannot promote normal growth is suggested by the finding that this protein contains only a very small quantity of the amino acid lysine. Osborne and Mendel observed actually that gliadin fed with supplementary amounts of lysine affords an amino acid mixture fully satisfactory to meet the needs of a normal rate of gain in body weight.

These and many other instances in which chemical studies of amino acid composition of a protein were correlated with nutritional studies of its effectiveness in meeting the body's protein requirement have shown clearly that the nutritive value of a protein depends primarily upon the kinds and relative proportions of the amino acids into which it is resolved (hydrolyzed) by digestion. There are a few cases in which secondary factors may have some nutritional significance; but they are not of sufficient importance to warrant discussion here.

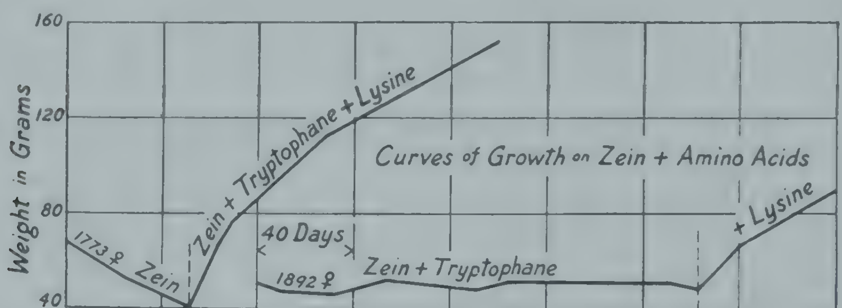

Fig. 11. Effect of adding to a diet containing zein as sole protein the amino acids lysine and tryptophan: showing that a "nutritionally incomplete" protein can support growth when supplemented by the essential amino acids which it lacks. (From the experiments of Osborne and Mendel.)

On the basis of tests, such as those of Osborne and Mendel already mentioned, in which young experimental animals were fed diets containing only a single, isolated protein, the following qualitative classification of proteins has been suggested and considerably used in teaching:

(1) "Complete" proteins: those which maintain life and provide for normal growth of the young when used as the sole protein food. Casein is the example of a complete protein in the preceding discussion. Other proteins in this group include lactalbumin of milk; ovalbumin and ovovitellin of egg; glycinin of soybean; excelsin of Brazil nut; and edestin, glutenin, and maize glutelin of the cereal grains.

(2) "Partially incomplete" proteins: those which maintain life but do not support normal growth. From the work of Osborne and Mendel already described, it is evident that gliadin represents this group.

(3) "Incomplete" proteins: those which, as sole dietary protein, are incapable of supporting either growth or life. Zein clearly belongs to this class, as does also gelatin.

Any such grouping of the proteins, however, should be used with discrimination, and with great care to insure an understanding of the

quantitative aspects of the experimental data, if misconceptions are to be avoided. Edestin is a conspicuous example of a "complete" protein, having served (in experiments of Osborne and Mendel) as the sole protein food of a family of rats for three generations. But when the percentage of edestin in the food mixture was considerably reduced, results like those above described for gliadin were obtained—the diet did not sup-

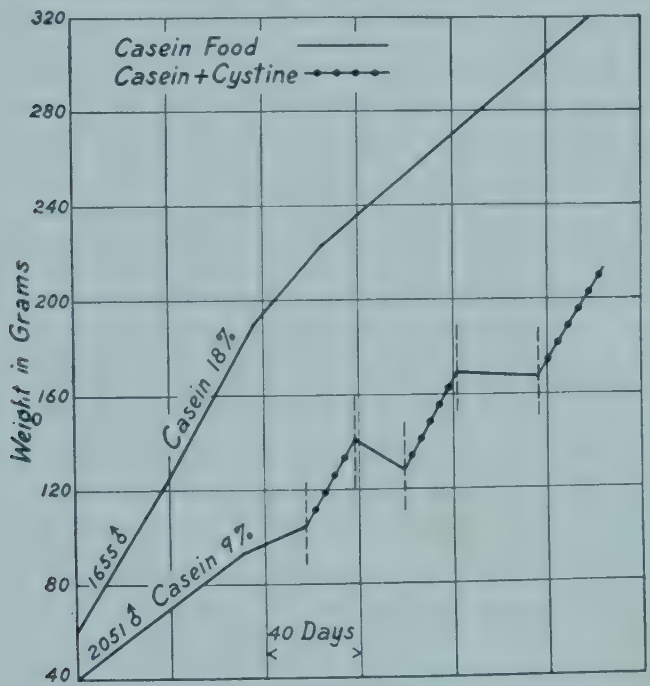

Fig. 12. Effect on growth of reducing the proportion of casein in the diet; and of feeding the amino acid cystine in addition to the lower level. This experiment of Osborne and Mendel illustrates the facts: (1) that a protein which at a liberal level of intake (here 18 per cent) supports normal growth may be unable to do so when fed in reduced proportion (here 9 per cent); and (2) that, as explained in the text, under certain circumstances growth may be promoted by the addition of a socalled nutritionally dispensable amino acid (in this case cystine).

port a normal rate of growth, but this could be secured by adding lysine to the food mixture. Similarly casein when fed in reduced proportion to the total food mixture did not support normal growth; but growth became normal when cystine was added (Fig. 12.) Thus "complete" proteins may behave as "partially incomplete" when fed in reduced proportion. It is also to be remembered that varying rates of growth in different species (not to mention other differences) make inadmissible any broad generalizations as to the proportions in which any protein should be fed

to species other than that with which its "completeness" or "incompleteness" has been demonstrated.

Stepwise Gains of Knowledge Through Experimentation

Out of studies such as are illustrated by Figs. 10 and 11 grew also another concept. While body proteins contain about twenty kinds of amino acids, each of which is in this sense essential to the body structure, only certain specific ones of these are *nutritionally essential* (*nutritionally indispensable*) in the sense that they must be supplied by the nutriment before the body can grow (form new protein) at a normal rate, whereas others need not be supplied by the food since they can be derived from other materials ordinarily available within the body. For instance, the amino acids glycine, lysine, and tryptophan are essentially absent from the protein zein. As we have seen (Fig. 11), the feeding experiments with zein as sole dietary protein afford evidence in favor of classifying tryptophan and lysine as nutritionally indispensable, for growth occurs only when both of these amino acids are fed in addition to zein. Glycine, on the other hand, appears from this experiment to be nutritionally dispensable, inasmuch as a zein-lysine-tryptophan mixture, which supplies no glycine, can nevertheless satisfy the amino acid requirements for normal growth.

However, there are not many instances where the nutritional indispensability of an amino acid can be tested so simply as that of the three just discussed. Known cases of *complete absence* of one or two amino acids from an otherwise satisfactory protein are comparatively rare; and, furthermore, methods for the determination of some of the amino acids still fall short of perfection. While it may be possible to show that a given amino acid *is* nutritionally essential without having excluded it altogether from the basal diet, one cannot conclude that a given amino acid *is not* nutritionally essential unless it can be established that normal growth is possible on a diet which is beyond doubt completely devoid of the amino acid in question. Otherwise the possibility remains that the organism does require a dietary supply of the amino acid but that the amounts needed are so small that they can be satisfied by the very low concentration afforded by the basal diet.

It has therefore been necessary to find other means for effectively

excluding from the diet the amino acid whose status is under investigation, while supplying to the experimental animal all of the other factors required for normal nutrition. The attainment of this objective, and the resulting classification of the known amino acids as "nutritionally essential" or "nutritionally non-essential" is largely the result of many years devoted to this field of investigation by William C. Rose and his associates at the University of Illinois. These investigators put together mixtures of purified amino acids in the proportions in which they were supposed to occur in some nutritionally "complete" proteins; with the idea that such a mixture when introduced in place of protein in an otherwise suitable diet should permit normal growth, and that one might then proceed to investigate the nutritive importance of individual amino acids by omitting them, one by one, from the mixture and ascertaining the effect of this change upon growth. Casein was chosen as a pattern to be followed in compounding such a mixture of amino acids, but it was soon found that all of the *then* known amino acid components of this protein fed together in the appropriate proportions failed to support good growth, although, under otherwise identical conditions, casein itself gave excellent results. The search for an explanation of this observation led ultimately to the discovery of the amino acid *threonine* which had not previously been identified as a component of proteins. This discovery—in itself of great scientific interest—solved the final difficulty in the way of preparing a synthetic mixture of purified amino acids which can fully meet the nutritional need for protein. Then, by successively excluding one or another amino acid, Rose was able to show that ten amino acids satisfy his definition of "an indispensable dietary component as one which cannot be synthesized by the animal organism, out of materials *ordinarily available,* at a speed commensurate with the demands for *normal* growth." If any one of these ten socalled "nutritionally essential" amino acids is lacking in the amino acid mixture, normal growth will not occur. But if all ten of these are provided in suitable amounts, the body can form from them the remaining amino acids which enter into the composition of its proteins. The ten amino acids now called "nutritionally essential" in the sense of Rose's definition are shown in Table 9.

Recently, similar experimentation with human infants has been begun. L. Emmett Holt, Jr., and his associates have developed a

TABLE 9. *Amino Acids Which Are Nutritionally Essential or Indispensable for Growth in the Sense Explained in the Text*

Arginine	Lysine	Threonine
Histidine	Methionine	Tryptophan
Isoleucine	Phenylalanine	Valine
Leucine		

purified diet for infants in which the protein moiety is provided by pure amino acids. By altering the amounts of threonine and phenylalanine in this diet, they showed both of these to be "nutritionally essential;" and estimated the approximate minimum requirement of infants to be 60 and 90 milligrams per kilogram per day, respectively, of these two amino acids.

In addition to nutritional indispensability for growth a further discrimination among the amino acids has been made. Rose has proceeded to establish which of the amino acids must be supplied for *adult maintenance*. In this case he was able to experiment with human beings, who were fed diets as highly purified as those of the most meticulous animal experiments. Rose found that young male graduate students could maintain their stocks of body protein on diets containing no protein but a mixture of the ten amino acids necessary for normal growth (Table 9). One or another of these amino acids was then removed from the diet and the results noted. Arginine and histidine could be withheld without deleterious effect on the "protein balance;" but when any of the other eight amino acids was lacking, the body began to lose nitrogen (protein) sharply. Thus, *isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan,* and *valine* all are *nutritionally essential* in the *maintenance of nitrogen* (protein) *equilibrium* in normal *adult man.*

Apparently adult man can make arginine and histidine from other essential amino acids or from other substances available in metabolism at a sufficient rate to meet the needs of normal maintenance. Whether, or under what conditions, the growing child (like young experimental animals) requires arginine or histidine or both, and whether in adults special circumstances such as pregnancy, lactation, or disease, cause demand for certain amino acids not needed for normal maintenance, are not yet known.

That the criterion of indispensability of an amino acid is by definition the inability of the body to form it *fast enough for normal growth* should be kept in mind if confusion and misapprehension are to be avoided. Thus, arginine, which the body can indeed form, but not fast enough for normal growth, is classified as indispensable.

Essential amino acids may be thought of as used in two distinct ways:

(1) *unchanged*, as "building stones" for body proteins, enzymes, etc., for which purpose the particular indispensable amino acid and it alone may be used;

(2) *as precursors*, from which are formed the socalled dispensable amino acids.

It would seem logical to expect that the amounts of the indispensable amino acids which are required will be increased in proportion as the dispensable amino acids of which they are precursors are lacking in the food; and conversely, the need for them should be somewhat diminished if the diet provides liberal amounts of the socalled dispensable acids. Whether or not this merits consideration from a practical point of view will depend upon how specific is the relationship between indispensable and dispensable amino acid.

It is shown to be of great importance in the case of the sulfur-containing amino acids, methionine and cystine. According to the usual definition, methionine is characterized as indispensable, cystine as dispensable. Methionine, however, is the only known material ordinarily presented to the body from which cystine may be formed. Thus, of all the usual dietary constituents, methionine alone can fulfill the bodily functions for which methionine is required; and only methionine or cystine can supply the cystine needed for body processes. What, then, if a diet supplies a limited amount of methionine—enough, let us say, to meet the growth requirements for methionine *per se* but not sufficient to provide the needed cystine? Whether or not growth can occur under such circumstances will depend directly upon the amount of cystine which the diet supplies. This is illustrated, for example, by Osborne and Mendel's experiments with low casein diets (Fig. 12). Experiments at the University of Illinois showed that, in terms of the amounts of methionine which were required in the absence of cystine, fully one-third of the methionine required for growth could be replaced by cystine, while 80 to 89 per cent of the adult maintenance in man could be provided in the form of cystine. This observation is of real practical importance, in view

of the reports that in certain regions of the world, methionine is more likely than any other amino acid to be in insufficient supply in the foods consumed. When the cystine present in such diets is taken into consideration, the potential shortage of methionine appears somewhat less critical.

Similarly, tyrosine has been found to "spare" phenylalanine, both for growth and for maintenance. Womack and Rose (1946) found that only about one-half as much phenylalanine was required by rats for maximum growth when liberal amounts of tyrosine were provided as when tyrosine was absent from the diet. And Rose and Wixom (see paper XIV of series by Rose and associates, 1950–1955) found that for maintaining the protein balance of adult men on purified diets, tyrosine could replace 70 to 75 per cent of the phenylalanine required when there was no tyrosine in the diet.

How Much Protein is Needed for Adult Maintenance?

Maintenance requirement is the amount required for nutritional equilibrium in the body.

Whether the body is in protein equilibrium or is gaining or losing protein, is ascertained by means of *nitrogen balance experiments*. These are experiments in which one determines, by means of chemical analyses of food and excreta, the amounts of nitrogen which enter and which leave the body, so that intake may be compared with output in a manner analogous to the balancing of a bookkeeping account.

We may say that the balance has been determined whenever the quantitative relation of intake and output has been ascertained. The body is said to be *in equilibrium* when intake and output are alike. The expression "in balance" is somewhat ambiguous because one has "determined the nitrogen balance" whenever the intake and output have been ascertained and regardless of whether the data show equilibrium or not. Thus we meet the expression "plus balance" or "positive balance" when the data show that the body is gaining—and "minus" or "negative" balance when the body is losing—nitrogen or whatever other element may be under similar consideration (as phosphorus, calcium, and iron will be in subsequent chapters). The *smallest* intake which will support equilibrium,

in a series of properly planned experiments, should indicate the body's maintenance requirements in the strict sense of the term.

Using nitrogen as a practicable and sufficiently accurate measure of protein, each gram of nitrogen corresponds to approximately 6.25 grams of protein inasmuch as the mixed proteins of the body and of the food contain on the average 16 per cent of nitrogen. Nitrogen balance experiments, then, can be made to show the amount of protein which the food must furnish to maintain protein equilibrium.

In 1920, the available data which appeared to be applicable to the problem of the normal adult requirement were studied. About one hundred such cases were found, and these gave a mean result of 0.634 gram of protein per kilogram of body weight per day with no significant difference per unit of body weight between the sexes. Figured to the conventional basis of a body weight of 70 kilograms (154 pounds) this average finding was 44.4 grams of protein per man per day.

The evidence of more recent investigations is to revise downward the figure for minimum maintenance need. Bricker, *et al.* (1945) found 42.1 grams per day as the need for the 70-kilogram man when white flour was the only source of protein, and 27.6 grams per day when 47 per cent of the protein was of animal origin. And in an extensive series, Hegsted, *et al.* (1946) found 32.4 grams per 70 kilograms of body weight as the minimum need for maintenance on an all-vegetable mixed diet, and 27.1 grams when one-third of the protein was replaced by protein from animal sources.

All of the generally accepted *dietary standards* and *recommended allowances* for protein lean toward liberality as contrasted with actually demonstrated need.

A common custom for many years was to add 50 per cent to the above mentioned average of 44.4 grams of the 1920 compilation, thus arriving at a "standard" of 67 grams per 70 kilograms of body weight, or, in round numbers, *one gram of food protein per day for each kilogram of body weight.*

This latter—65 grams of protein for the 65–kilogram man and 55 grams of protein for the 55–kilogram woman who is neither pregnant nor lactating—is the daily allowance recommended by the Food and Nutrition Board of the National Research Council (1953).

As can be seen from Table 48 in the Appendix, these allowances for maintenance of fairly active individuals provide: for men, 8 to 10 per cent of the total calories in the form of protein, and for women, about 10 to 12 per cent.

Muscular work supported by an ample intake of food calories need not increase the amount of protein metabolized. In other words, the extra calories for the work can be supplied by increased carbohydrate (or carbohydrate and fat) without increase of protein. Sometimes it appears more practical, or is found more acceptable, to provide for the increased muscular activity by simply increasing the amount of food of the accustomed kind; but where cost must be given utmost consideration it may well be remembered that this practice is unnecessarily extravagant.

Protein needs of the elderly. In contrast with the statement often made that protein is not apt to be deficient in the American dietary, are reports of frequent negative nitrogen balances among elderly people and indications that some of the disabilities of old age may be mitigated by increased protein allowances. There is a tendency in recent writings on geriatrics to recommend that the protein intake of the elderly be held at about the same level recommended for younger adults, the reduction in total calories being accomplished at the expense of carbohydrates and (perhaps especially) fats.

Maintenance Requirements of Specific Amino Acids

As explained above, Rose of the University of Illinois demonstrated in a qualitative way that eight amino acids are essential for the maintenance of nitrogen equilibrium in normal adult men. Then followed an impressive series of quantitative balance experiments in which many human subjects were maintained over long periods of time on diets composed of highly purified foodstuffs similar to those fed laboratory animals, in order to determine, specifically for each of these eight amino acids, how much must be provided in order to maintain nitrogen equilibrium. In each case, the other seven amino acids necessary for adult maintenance were provided in adequate amounts, and the diet furnished sufficient extra nitrogen to permit the synthesis of the non-essential amino acids, as well as a liberal intake of calories.

In presenting the summary of the findings in this series, Rose and his associates have selected as the "*tentative* minimum requirement" of any amino acid the highest value which they observed in any subject,[2] and have proposed as "definitely a *safe* intake" a value

TABLE 10. *"Minimum" and "Safe" Intakes of Essential Amino Acids for Normal Maintenance in Man When Diet Furnishes Sufficient Nitrogen for Synthesis of Non-essential Amino Acids* (adapted from Rose, *et al., Journal of Biological Chemistry,* volume **217**, page 992, 1955)

Amino Acid	*Value proposed* tentatively *as minimum grams per day*	*Value which is definitely a* safe *intake grams per day*
Tryptophan	0.25	0.50
Phenylalanine	1.10*	2.20
Lysine	0.80	1.60
Threonine	0.50	1.00
Valine	0.80	1.60
Methionine	1.10†	2.20
Leucine	1.10	2.20
Isoleucine	0.70	1.40

* On diet devoid of tyrosine. Presence of suitable amounts of tyrosine may reduce the phenylalanine requirement by 70 to 75 per cent.

† On diet devoid of cystine. Presence of suitable amounts of cystine was found to reduce by 80 to 89 per cent the amount of methionine required.

twice this "tentative minimum requirement." *Safe* as here used refers to an intake high enough to allow for individual variations in the amount of the amino acid required to maintain nitrogen equilibrium. Rose has emphasized repeatedly that his experiments do not permit assessment of the *optimal* amino acid intakes for man. Estimates of the essential amino acid requirements of women

[2] Note that this method of interpretation selects the highest need noted for any individual as the "tentative minimum requirement" for the group; in contrast with the practice of most earlier estimates of the need of various nutrients by means of balance studies, in which the *average* of the amounts needed by all individuals has been designated as the minimum requirement. Thus Rose's estimate, even of minimum requirement, includes some margin of safety to cover individual variability which obviously is not present in estimates on the latter basis.

are beginning to appear, as for example, the following by Leverton and her associates (1954, 1956) for "young college women"

threonine	0.31 gram	
tryptophan	0.16 gram	
valine	0.65 gram	
phenylalanine	0.22 gram	(when 0.9 gram of tyrosine is included in the diet)
leucine	0.62 gram;	

by Swendseid and associates (1956) for young women

methionine-plus-cystine	0.55 gram
isoleucine	0.45 gram;

and by Jones, Baumann, and Reynolds (1955) for "mature women"

lysine	0.63 gram	
methionine	0.23 gram	(when 0.5 gram of cystine is included in the diet).

In a final paper of the series entitled "The Amino Acid Requirements of Man" Rose and Wixom (1955) reported that nitrogen equilibrium could be achieved on a total intake of 3.50 grams of nitrogen, when all of the eight essentials were provided at the safe level[3] and when glycine provided the extra nitrogen for synthesis of the non-essentials. This amount of nitrogen is only half to three-fourths as much as the total intake corresponding to the minimum protein requirement as determined by the nitrogen-balance experiments summarized earlier, in which mixtures of natural foods supplied the nitrogen intake. It might thus appear that when all of the essential amino acids are provided simultaneously and in balanced relation to one another and to the body needs, there may be more efficient utilization than when presented in such chance proportions as the ordinary mixed diet supplies.

Recommendations for Growth, Pregnancy, and Lactation, as well as for Maintenance

Growth and development of infants and children implies the building into the body of large amounts of protein, notably in the

[3] It may be calculated that the amount of nitrogen provided by safe intakes of the eight amino acids essential for maintenance totals 1.46 grams.

muscular structures but to some degree in every active tissue. Growing children therefore require far more protein[4] in proportion to their body weight than do adults, who need provide only for maintenance. The National Research Council recommendations are:

For infants under one year, 3.5 grams of protein per kilogram of body weight per day.

As children grow older and their growth rate diminishes, the amount of protein needed relative to their body weight becomes progressively less, until toward the end of the growth period the recommended intake amounts to only about 1.5 grams of protein per kilogram of body weight. By age groups, the National Research Council's recommendations are:

For children: 1–3 years old, 40 grams of protein per day
4–6 years, 50 grams
7–9 years, 60 grams
10–12 years, 70 grams
13–15 years: girls, 80 grams; boys, 85 grams per day
16–20 years: girls, 75 grams; boys, 100 grams per day.

These recommended allowances are not to be interpreted too literally and rigidly but as general guides which imply that more protein may be needed during bodily development than after it has been completed; and that the high point of body-building need will usually be passed at an earlier chronological age in girls than in boys.

When a woman is providing for growth of a fetus within her, or is nourishing a rapidly growing infant in lactation, her need for protein is increased substantially. Thus, compared with 55 grams of protein for maintenance in women, the National Research Council's Food and Nutrition Board recommends:

For women in the last third of pregnancy, 80 grams; and in lactation, 100 grams of protein per day.

There is evidence that adequacy of protein intake during pregnancy may be of importance in determining the success of the pregnancy and the vigor of the offspring.

[4] Recent reports on the infant's need for threonine (Pratt, *et al.*, 1955) and phenylalanine (Snyderman, *et al.*, 1955) suggest that, during rapid growth, the need for essential amino acids may increase in even greater proportion than the need for total protein.

It can be computed from Table 48 in the Appendix that the National Research Council recommendations provide a somewhat larger proportion of the calories as protein in the case of infants and children (12 to 14 per cent as protein) and of girls and pregnant and lactating women (12 to 13 per cent) than in the case of boys (11 per cent) and of adults in maintenance (men, 8 to 10; women, 10 to 12 per cent).

These differences are small enough, however, so that where one is planning a dietary for a family or larger population group, one may arrive at about the same result by the much used practice of dietitians to determine first the total food calories to be supplied and then add that "about 10 per cent" or "from 10 to 15 per cent" of the calories should be in the form of protein. The allowance of 10 per cent is held to be ample by those who follow Chittenden in his advocacy of "physiological economy in nutrition" or who feel particularly the need of economy as to cost, while an allowance of from 10 to 15 per cent is sufficient to provide for those whose scientific judgments or whose temperaments lean toward relatively high protein intake.

Protein Contents of Foods

In Table 46 of the Appendix, the total protein contents of some 220 items of raw and cooked foods are given as grams of protein per 100 grams of edible material. From this table the short Table 11 below was drawn, in which typical foods of widely different types are listed in simply alphabetical sequence and their protein content given in percentage of the edible portion of the food, moist or dry according to the condition in which it is usually sold. Analogous tables in other chapters may be arranged in different sequence or expressed on different bases, to give the reader practice in comparing foods from different points of view.

To What Extent Does Food Selection Influence the Nutritive Efficiency of the Protein Mixture which the Dietary Affords?

The problem of this chapter being how to meet the need for protein, its text should include a brief further consideration of the

TABLE 11. *Protein Contents of Edible Portion of Typical Foods*

Food	*Protein per cent*	*Food*	*Protein per cent*
Almonds	18.6	Eggs	12.8
Apples, fresh	0.3	Kale	3.9
Apricots, dried	5.2	Milk	3.5
Bacon, medium fat, uncooked	9.1	Oatmeal	14.2
Beans, dried	21.4	Oranges	0.9
Beef, round, lean	19.5	Oysters (solids and liquor)	6.0
Bread, white	8.5	Peanuts, roasted	26.9
" whole wheat	9.3	Potatoes	2.0
Cantaloupe	0.6	Rice, white	7.6
Carrots	1.2	Salmon, canned	20.2
Cauliflower	2.4	Sweetpotatoes	1.8
Cheese, Cheddar type	25.0	Tomatoes	1.0
		Turnip greens	2.9

practical effect of differences in food selection on the total amount of protein required.

It has long been known that individual proteins vary widely in the efficiency with which they are utilized by the body, and this is true even between different "nutritionally complete" proteins.

Thus, in 1916 Osborne and Mendel published quantitative measurements of the relative efficiency (for support of growth in young rats) of some of the "complete" proteins. The rate of gain obtained with 8 per cent of lactalbumin required 12 per cent of casein or 15 per cent of edestin; or, as they also stated the results, "to produce the same gain in body weight, 50 per cent more casein than lactalbumin was required, and of edestin nearly 90 per cent more."

A large part of the explanation of such differences in biological efficiency can be found in the relative proportions in which they supply the nutritionally essential amino acids. However, lest we attribute undue weight to the differences between *individual* proteins, we should remember that practically all foods except gelatin contain more than one kind of protein, and the natural mixtures of proteins which staple articles of food contain do not differ nearly so much in amino acid make-up and resulting nutritive value as do

the individual proteins when separated and examined as isolated substances. Thus, *one* of the proteins of maize, zein, as we saw earlier, is a nutritionally incomplete protein, being essentially devoid of tryptophan and lysine. Yet *whole maize* is found by feeding tests to be nutritionally complete, and chemical analysis of its amino acid composition (see Table 30, Chapter 19) shows correspondingly a complete assortment of nutritionally essential amino acids.

There is thus less danger of an incomplete assortment of amino acids in even a single natural food than in a single isolated protein. Nevertheless, the mixtures of proteins found in certain articles of food have higher nutritive efficiency than the natural mixtures in certain other foods, because they yield the essential amino acids in proportions which approximate more closely the needs of the body. Thus, experiments such as those of Osborne and Mendel indicated that proteins of animal origin are, as a class, superior in nutritive efficiency to most of those derived from plants. Of animal proteins, those of whole milk and whole eggs share the first place. Next come the animal tissue proteins, among which those of liver and kidney probably have a higher value than those of muscle. Among the nutritionally important plant protein mixtures, those of the cereal grains, though inferior to most animal proteins, have nevertheless been found to possess a higher value than those of white flour. The natural protein mixture of milk is much more efficient than those of the grains, when each food is fed separately as sole source of protein to rapidly growing young animals. Yet when grains and milk are fed together in favorable proportions, their proteins so supplement each other in furnishing the nutritionally essential amino acids that the combination may be practically as efficient as the milk proteins alone. This *supplementary relationship* between proteins is of great importance both nutritionally and economically, since it makes possible the full utilization of the low-cost proteins of grains and other vegetable foods, provided only that they are fed in combination with sufficient amounts of those foods which reinforce their content of certain essential amino acids.

Here it should perhaps be noted that differences in nutritive effectiveness or biological value which appear considerable when determined by the effect on growth rate of a rapidly growing species like the rat, may however appear less marked when a more

slowly growing species—such as man—is under observation. Thus, studies by Widdowson and McCance (1954) of the growth of German war orphans fed diets in which the proteins were almost exclusively of plant origin *but which were well supplemented with vitamins and minerals* led them to conclude that: "diets in which 75 per cent of the calories were derived from wheat flour and 21 per cent from vegetables, and which contained only 8 grams of animal protein per day, provided undernourished children aged 5–15 years with all of the nutrients required for a high rate of growth and development for a period of 18 months." Possibly, the nutritional superiority traditionally attributed to "animal protein" in human dietetics may have been due in large part to vitamins and minerals which the animal sources provided.

In the maintenance of full grown tissues, there need be no special anxiety regarding the adequacy of the amino-acid mixture yielded by the proteins of mixed diets such as are common in this country. Indeed, the proteins of white flour alone were found by Bricker, *et al.* (1945) to be adequate to this need (though, to be sure, a higher total protein intake was required than on a mixed diet); while Hegsted, *et al.* (1946) found that on an entirely vegetarian diet only one-fifth to one-sixth more total protein was required for nitrogen equilibrium than on a diet in which one-third of the protein was of animal origin. That differences in effectiveness for adult maintenance, though measurable, are of limited practical significance was again confirmed in recent work of Hegsted and associates (1955) in which supplementing all-vegetable diets with lysine and methionine, the supposed "limiting amino acids," only moderately improved the nutritional effectiveness of the vegetable diet.

In cases in which new protein must be built up in the body, e.g., growth, pregnancy and lactation, convalescence from a wasting disease, or feeding to build up a chronically undernourished person, the choice of proteins may become a matter of considerable importance. The proteins of milk and eggs are the ones best suited for conversion into body proteins. For this *and other reasons* it is highly desirable that milk or eggs or both be provided abundantly in the diet of growing children, of pregnant or nursing women, and of all people who require "building up."

Essential Amino Acids in Certain Foods and in American Dietaries

Block and Bolling (1951) have collected information and made estimates of the *approximate* essential amino acid contents of the proteins from many sources. Some of their figures are given in Table 30 of Chapter 19, expressed as grams of amino acid per 16 grams total nitrogen or 100 grams total protein; while we have used such data together with figures for the percentage of total protein to compute the essential amino acid values expressed as grams per 100 grams of food as eaten, in Table 12 below.

TABLE 12. *Estimated Essential Amino Acid Values of Typical Foods: Grams per 100 Grams of Food*

	Lysine	*Phenylalanine + tyrosine*	*Tryptophan*	*Methionine + cystine*	*Threonine*	*Leucine*	*Isoleucine*	*Valine*
Beans, baked (½ cup)	0.38	0.45	0.046	0.13	0.23	0.41	0.32	0.32
Beef, hamburg (1 large cake)	2.2	1.98	0.308	0.97	1.10	1.76	1.32	1.21
Bread, enriched (4–5 slices)	0.22	0.80	0.076	0.35	0.25	0.63	0.37	0.37
Cheese, cheddar (⅞ c., grated)	2.1	3.35	0.375	1.00	0.90	2.25	1.82	1.92
Eggs (2 medium)	0.90	1.38	0.192	0.82	0.55	1.18	0.98	0.92
Frankfurters (2, cooked)	1.4	1.26	0.196	0.62	0.70	1.12	0.84	0.77
Greens (½ c., cooked)	0.17	0.33	0.068	0.14	0.17	0.31	0.16	0.16
Milk, whole fluid (⅜ c.)	0.30	0.40	0.05	0.15	0.16	0.38	0.26	0.24
dried, skimmed (1 c.)	3.10	4.09	0.53	1.50	1.67	3.91	2.67	2.49
Oatmeal, cooked (⅜ c.)	0.08	0.23	0.03	0.09	0.08	0.18	0.11	0.12
Peanut butter (6 tablespoons)	0.78	2.48	0.26	0.68	0.42	1.75	1.20	1.15
Potato, baked (1 medium)	0.20	0.14+	0.05	0.06+	0.17	0.23	0.09	0.13

Using such approximations in conjunction with figures of per capita intake of various kinds and types of food, estimates of the essential amino acid intake can be made. Such a calculation for the

average United States diet of 1937–41 showed a total per capita intake of 89 grams of protein with all of the amino acids essential to adult maintenance provided at levels far above those set by Rose as "safe." The quality of the protein mixture of this average diet was such that even had the intake level been reduced to 40 grams of protein per day, "safe" levels would have been provided for all of the amino acids essential for adult maintenance, with the exception of methionine. Counting cystine and methionine together, the intake of this essential falls about midway between Rose's estimate of "minimum requirement" and that for a "safe" intake. Similar calculations applied to the statistics for food intake among the lowest income urban population (which had the least favorable protein intake of the four groups studied) showed again a protein content which, though lower than the national average (74 grams), was of such nutritive quality that, had it been reduced to 40 grams per day, it would still have supplied "safe" intakes of all the essentials except methionine, and this would have been supplied at a level at least 20 per cent above the tentative "minimum requirement."

From Table 30 in Chapter 19 it can be predicted that populations living on diets lower in total protein and consisting much more largely than ours of cereal products such as highly milled wheat and maize might tend toward low intakes of lysine and tryptophan as well. Interestingly enough, oats and even white rice are relatively richer in lysine and tryptophan than are white flour and corn grits. The latter fact may be of great importance for the large portion of the earth's population living so largely on rice.

A few rather interesting differences between the proteins from the various food sources come to light when one considers the amounts of each essential amino acid that 40 grams of the protein would provide, and compares these with the estimates of "minimum" requirement.

On this basis it would appear that the foods of animal origin, i. e., meat, fish, liver, eggs, and milk all carry their full quota of the amino acids essential to adult maintenance.

Whole wheat, oats, and rice carry their quota, so defined, of the essential amino acids but the margin in the case of methionine plus cystine is rather slight and lysine also is relatively less abundant than the other essentials. The same is true of whole maize, which, however, has a relatively less abundant content of tryptophan also.

White flour falls somewhat—and corn grits fall notably—below the quota in lysine, and both have only a slight margin of tryptophan and of methionine plus cystine.

Peanuts are about on the borderline with respect to meeting the quota of methionine plus cystine, and have only a moderate margin of threonine, in this latter respect differing conspicuously from the other foods under consideration.

Soybeans, green leaves, and potatoes compare favorably with the animal proteins as to the relative amounts of the essential amino acids which they provide (except that, in the case of the soybeans the margin of cystine plus methionine is less wide); and the tryptophan content is uniquely high in the case of the leaves and potatoes. The proteins of soybeans, leaves, and potatoes are, in fact, especially effective for supplementing highly milled wheat and maize products at their point of greatest weakness, i. e., lysine, and helpful in contributing the tryptophan in which also these refined products are relatively low.

The finding that methionine plus cystine appears to be the critical amino acid in ordinary American diets (at least so far as maintenance is concerned) seems to be due to the fact that eggs alone of the ordinary items of the diet contain a proportion of methionine plus cystine which is generous with respect to the apparent needs for adult maintenance.

It must be emphasized that the foregoing discussion of effectiveness of various proteins applies to the needs for adult maintenance. The relative needs for the different amino acids may be different in growth. Thus, there are suggestions in the work of Rose that in growth the need for lysine and threonine may be considerably greater (relative to that for the other amino acids) than it is for maintenance.

It should be emphasized further in closing this section, as it was at the start, that the estimates both of the amino acid composition of proteins and of the adult maintenance requirement are still tentative, and one may expect revision of either or both in the years just ahead.

Importance of the Protein Problem on a Worldwide Basis

Clinical observations and dietary surveys indicate that in our country (and perhaps for what have been called the "privileged countries of the world") instances of real shortage either of total protein or of specific essential amino acids are relatively rare in practice.

This is not the case for the vast underprivileged areas of the earth; where it may represent one of the most pressing nutritional problems. In 1953, the Joint Food and Agricultural Organization/World Health Organization Expert Committee on Nutrition reported: "In the field of medicine, public health and medical research, attention has recently shifted from disease due to deficiency of vitamins and minerals to what can provisionally be called protein malnutrition. This term . . . is used here to indicate in general a state of ill-health occurring where diets are habitually poor in protein, while they are more nearly adequate in calories . . . The concept includes the effects of deficiency in the quantity of protein consumed, of imbalance of amino acids, and of deficiency of factors such as vitamin B_{12}, commonly found in foods in association with animal protein and concerned with protein metabolism."

Kwashiorkor, a nutritional disease affecting primarily infants at the post-weaning stage and occurring in underprivileged populations widely distributed over the earth, has been attributed largely to protein malnutrition, in the sense the term was defined above to include factors affecting protein metabolism and factors customarily associated with protein foodstuffs as well as proteins and their amino acids *per se*. Studies on kwashiorkor and other conditions ascribed to protein malnutrition are reviewed by Brock and others listed among the Suggested Readings which follow.

EXERCISES

1. Feed parallel groups of young rats, starting at 3 to 4 weeks of age: (*a*) a mixture of 90 parts white flour, 9 parts butter, and 1 part table salt; (*b*) a mixture of 60 parts white flour, 30 parts milk powder, 9 parts butter, and 1 part of the same table salt. While the introduction of the milk will have enriched the diet in certain mineral elements and vitamins as well, the difference in growth during the first three or four weeks of this experiment may be attributed chiefly to the milk proteins.

2. Feed parallel groups of young rats, starting at 3 to 4 weeks of age: (*a*) bread moistened with its weight of milk; (*b*) bread of the same kind moistened with 5–per cent solution of milk sugar and spread with as much butter as corresponds to the milk used in (*a*). If the contrast here found differs from that found in the preceding Exercise, how do you explain the difference?

3. Plan experiments making use, if circumstances permit, of socalled "synthetic" diets (mixtures of artificially purified substances) between

which the sole differences shall be: (*a*) an individual protein, e.g., casein; (*b*) an individual amino acid, e.g., lysine.

4. If facilities are available, carry out the experiments described in Exercises 1 and 2 and those planned in Exercise 3, continuing them as long as time permits, with daily feeding, watering, and casual inspection of the animals; and at least weekly weighings and careful physical examination.

In addition to the promptly-developing differences in growth, attributable to the protein (amino acid) factors discussed in the foregoing chapter, it is possible that a long-continued comparison would develop other effects which, after your study of the chapters which follow, you might be able to attribute to some mineral or vitamin factor.

5. Examine the literature for feeding tests in which the limiting amino acid of individual foods was determined. Was the finding what one would have predicted from the chemically determined data of Table 30? If not, what possible explanation can you suggest for the discrepancy?

6. Determine the cost of 10 grams of protein in the form of each of the following foods: beef hamburg, bottled whole milk, cottage cheese, dried beans, enriched bread, peanut butter, Cheddar cheese, canned pea soup.

7. Estimate the quantity of methionine-plus-cystine which \$0.30 will purchase in the form of: (*a*) eggs, (*b*) hamburg, (*c*) dry skim milk, (*d*) potatoes, (*e*) cabbage (use figure for "leaves" in Table 30 or "greens" in Table 12).

8. Compare various foods similarly as to economy as sources of lysine.

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7

MINERAL ELEMENTS AND REGULATORY PROCESSES IN NUTRITION

The Mineral Elements

In preceding chapters we have discussed the composition and nutritive functions of foods principally in terms of the organic nutrients: carbohydrates, fats, and proteins. This has involved consideration of the elements carbon, hydrogen, oxygen, and nitrogen, which, as Table 13 shows, are the elements most prominent in the body's structure. In this chapter we shall be concerned with the other chemical elements regularly found in the body which, although most of them are present there in much smaller quantities than the four elements just referred to, are nevertheless essential to its normal functioning.

These other elements are commonly designated as the *mineral elements* or the *inorganic foodstuffs*. But the use of such terms should not be understood to imply that these elements necessarily occur and function exclusively as inorganic or mineral compounds. For example, the most prominent compounds of sulfur in the food and in the body are the amino acids cystine and methionine which have already been considered as constituents of the proteins. Yet although sulfur thus enters, and functions in, the body almost entirely as organic compounds it is, in the normal oxidation processes of the body, ultimately converted into the inorganic compound, sulfuric acid or sulfate ion, and as such becomes an important factor in the mineral metabolism.

Which Mineral Elements Are Essential?

It cannot be stated with certainty exactly how many of the mineral elements found in the body are indispensable to its normal

structure or functioning; and how many are present merely through accidental introduction from the environment. *All eleven mineral elements* for which figures are given in Table 13 and also *cobalt, zinc,* and *molybdenum* are now definitely regarded as essential.

With regard to the question whether other elements are essential it seems clear that any diet which is adequate in the unquestioned essentials will almost certainly provide the traces at most that may be required of mineral elements whose importance is still

TABLE 13. *Estimated Approximate Elementary Composition of the Adult Human Body*

Element	*Percentage*	*Element*	*Percentage*
Oxygen	65.	Magnesium	0.05
Carbon	18.	Iron	0.004
Hydrogen	10.	Manganese	0.0003
Nitrogen	3.	Copper	0.00015
Calcium	2.2[a]	Iodine	0.00004
Phosphorus	1.2[b]	Cobalt	[c]
Potassium	0.35	Zinc	[c]
Sulfur	0.25	Molybdenum	[c]
Chlorine	0.15	Others of more doubtful status	
Sodium	0.15		

[a] Estimates vary widely.
[b] Percentage varies with that of calcium.
[c] Quantitative data seem insufficient for numerical expression here.

unknown. And from this fact it follows that any element needed only in such small amounts that the need of it is still in doubt is unlikely to be an actual limiting factor in nutrition, either in nature or in civilized life; so that from the functional viewpoint of present-day science the elements to which we give attention in nutritional study for practical reasons are also undoubtedly the ones of really major scientific significance.

How Do They Function?

The elements concerned in the mineral metabolism may exist in the body and take part in its functions in at least three kinds of ways:

(1) as constituents of the mineral matter of the bones and teeth, giving these structures their strength, rigidity, and relative permanence;

(2) as structural constituents of the soft tissues also, as illustrated by the fact that all the known tissue proteins contain sulfur, several of them as well as some other substances essential to cell structure contain phosphorus, and the outstandingly important hemoglobin of the red blood cells contains iron;

(3) as constituents of substances concerned in regulatory functions, as, for example, the salts held in solution in the body fluids and important in giving these their characteristic influence upon the functional capacities of muscle and nerve, their osmotic pressure, their solvent properties and consequent ability to transport the nutrients and their metabolites, and the property of supplying the material for the acidity or alkalinity of digestive juices while at the same time maintaining approximate neutrality in the blood and body tissues. Other aspects of their regulatory functions are the relations of certain mineral elements to enzyme action—as components of the coenzymes themselves or as activators of enzyme action.

Varied as they are, these functions are interrelated at many points; and several of the socalled mineral elements take part in more than one of these three types of function.

Calcium and *phosphorus* function importantly in all three ways, and the preponderance of calcium phosphate in bone and tooth mineral makes them elements which the body needs in relatively large amounts. The next Chapter will be devoted to them.

Iron, while occurring in much smaller amounts than calcium and phosphorus, may nevertheless be a real problem in nutrition, in the sense that if it is left to chance one does not always get enough. Inasmuch as the iron which enters into nutritional processes goes mainly to form hemoglobin, and *copper* has been found to play an essential role in the transformation of iron into hemoglobin, these two elements are discussed together in Chapter 9. Copper has, however, functions which are independent of its role in iron metabolism. It is involved in the action of certain enzymes.[1] And a bone disorder which appears to be a specific effect of dietary

[1] Such as tyrosinase, fatty acid coenzyme A dehydrogenase (a factor involved in the oxidation of fatty acids), and uricase.

copper deficiency has been described by Baxter and his associates (1953).

Iodine is an element which *in certain regions* is not sufficiently abundant to be safely left to chance, especially now that people commonly use such highly refined table salt. Here we meet a very special kind of nutritional problem, which seems best treated by itself in Chapter 10.

Chlorine, in the form of its salts, the chlorides, plays a very important part in the maintenance of normal conditions in the body. That we do not (and need not) take account of chloride content in our ordinary judgments and studies of food values is due to our practice of adding so much sodium chloride (as common salt) to our food in its preservation, in its preparation, and at the table.

The chlorides are among the most important of the body's *electrolytes*. These are substances which in water solution exist as electrically charged particles called *ions*. They function very significantly as regulators of body processes, both collectively, for example, in the control of the osmotic pressure of body fluids and hence of the passage of water into and out of the tissues, and *specifically*, as in their effect on the irritability of muscles and nerves (to be discussed below) and on enzymes.

Sodium chloride, being by far the largest constituent of the mineral matter of the blood, assumes special significance in the regulation of water exchanges in the organism. And, as Cannon emphasized repeatedly, these latter are more extensive and more important than may at first appear. He pointed out that "there are a number of circulations of the fluid out of the body and back again, without loss." Thus, for example, it is estimated that from a quart to a quart and one-half of water daily "leaves the body" when it enters the mouth as saliva; another one or two quarts are passed out as gastric juice; and perhaps a similar amount is contained in the bile and the secretions of the pancreas and the intestinal wall. This large volume of water enters the digestive processes; and practically all of it is reabsorbed through the intestinal wall where it performs the equally important functions of carrying in the digested foodstuffs. These and other instances of what Cannon called "the conservative use of water in our bodies" involve essentially osmotic pressure relationships in which the concentration of sodium chloride plays an important part.

Under our ordinary conditions of everyday living the body is apt to receive and excrete several grams of sodium chloride per day, the amount varying with individual taste as to salting of food at the table and usually ranging considerably higher than is needed for maintenance of approximate equilibrium. There is little to indicate that salt intakes within this range are injurious to normal persons, and, indeed, it is said that the Japanese regularly consume about three times as much salt as Americans.

There are, however, clinical conditions in which restriction of salt (or more particularly, of sodium) intake may be essential (as in congestive heart failure) or helpful (as in some cases of high blood pressure); and the suggestion has been made (Dahl and Love, 1954)—though not as yet generally accepted—that for some persons with a predisposition to essential hypertension (high blood pressure) excessive intake of salt may play an important part in the development of the disease. "Sodium-restricted Diets: The Rationale, Complications, and Practical Aspects of Their Use," is the title of a joint publication (1954) of the Food and Nutrition Board of the National Research Council and the Council on Foods and Nutrition of the American Medical Association, dealing with various aspects of this problem.

In contrast to conditions in which salt intake must be restricted, people engaged in occupations which induce profuse sweating may thereby excrete so much salt through the skin as to call (temporarily, at least) for an increased intake in food or drink.

Thus there are scientifically sound possibilities of occasions to safeguard the salt intake: sometimes against too much, and sometimes against too little. But most people at most times may eat their food "salted to taste" without anxiety in either direction; for the healthy body has power to adjust sodium chloride output to sodium chloride intake throughout a wide range.

Although the Food and Nutrition Board states that "potassium is especially abundant in both plant and animal tissues and does not need consideration as a dietary adjunct," there has been a growing interest in potassium deficiency both as produced experimentally in animals and as met with occasionally in the clinic (though, in the latter case, not as a result of simple dietary deficiency of this factor). Apparently the body is not as well equipped to maintain its stores of potassium as of sodium during times of shortage: for a

frequent consequence of starvation is the development of symptoms of potassium deficiency (Wilson and Sink, 1953). When tissue protein is broken down in semi-starvation or as a result of dietary protein lack, potassium also is lost from the body. And there is evidence, both from the clinic and from the experimental laboratory, that, in order to rebuild body proteins efficiently, potassium must be supplied (see Cannon *et al.*, 1952, 1953; Muntwyler *et al.*, 1953).

Potassium is especially prominent inside the cells of the body and soft tissues, while sodium predominates in the blood plasma and other intercellular fluids. And similarly (although their concentrations are much lower than those of sodium and potassium), magnesium is largely localized within the cells, while calcium is relatively more abundant in the fluids bathing the cells.

However, the body fluids contain some of all four of these elements, and upon the balance between them depends largely the characteristic influence of these fluids upon the elasticity and irritability of muscle and nerve. The experiments of Howell, Loeb, and others on the heart afford a classic illustration of the individual and joint regulatory effects of various salts and their ions upon muscle tissue. It is well known that heart muscle may be kept beating normally for hours after removal from the body when supplied, under proper conditions, with an artificial circulation of blood or lymph or a water solution of blood ash. The sodium salts, being most abundant, take the chief part in the maintenance of normal osmotic pressure, which is one requisite for the continued life of the heart tissue. Aside from this property, sodium salts have a specific influence. Contractility and irritability disappear if sodium salts are absent, but when present alone these salts produce relaxation of the muscle tissue. Calcium salts, also, although occurring in blood in very much smaller quantity, are absolutely necessary to the normal action of the heart muscle; while, if present in concentrations above normal, they cause a condition of tonic contraction, or "calcium rigor" in sharp contrast to the relaxation induced by sodium salts. Potassium salts, in the small quantities normally present, promote relaxation, through this effect tending to diminish the rate of heart beat; and in higher concentration cause a state of extreme relaxation known as "potassium inhibition."

Thus it is found that the alternate contractions and relaxations which constitute the normal beating of the heart depend upon a balance between calcium salts on the one hand and sodium and potassium salts on the other. Other active tissues of the body doubtless have analogous requirements as to inorganic salts.

In addition to the case just discussed, several other instances of socalled *ionic antagonism* might be cited. For example, *calcium* ion is in some measure antagonistic to *magnesium* ion. Thus, magnesium salts when administered in abnormally large quantities show a soporific and hypnotic action, which effect can be counteracted by the administration of calcium salts. Also the addition of magnesium to an otherwise well balanced ration tends to cause a loss of calcium from the body. And, conversely, experimental magnesium deficiency results in an abnormal accumulation of calcium in the soft tissues.

Similarly, a high intake of *potassium* salts increases the excretion of *sodium* salts. Since most vegetable foods are relatively rich in potassium, Bunge suggested that this fact may afford an explanation of the craving for common salt which man shares with the herbivorous animals. Conversely, the presence of relatively large amounts of sodium is such an important factor in aggravating the manifestations of potassium deficiency that it is sometimes said that sodium acts as a "toxic" ion in this condition.

Some of the mineral elements have individual and specific functions in addition to their cooperative activities already mentioned. For example, the presence of calcium salts is absolutely essential to the clotting of blood, while magnesium salts enhance the activity of the enzymes known as phosphatases and assist at certain stages in the metabolism of carbohydrates, as well as taking part in protein synthesis in the body.

The prominence of calcium and phosphorus in bone has already been mentioned. Smaller amounts of magnesium, potassium, and sodium appear likewise to be constituents of the skeletal structures.

The essential element *cobalt* functions as a component of vitamin B_{12} (*cobalamin*) which is considered in Chapters 9 and 14. Cobalt deficiency is occasionally a factor in practical livestock feeding.

Manganese also is essential to nutrition, presumably acting in part at least through its effect on certain enzyme systems.

Zinc, like so many others of the essential trace elements, has a role in several enzymic reactions.[2] New interest attaches to this element since the recognition (Tucker and Salmon, 1955) of zinc deficiency as a spontaneously occurring disease in pigs.

Molybdenum, a newcomer to the list of recognized essentials, functions importantly in plant nutrition in the processes whereby the nitrates of the soil become available for plant utilization; and in animal nutrition is involved in several enzyme systems.[3] Under some conditions it assumes practical importance in livestock feeding (Davis and Loosli, 1954; *Review*, 1955*d*).

Among elements not yet regarded as essential to normal nutrition, some – notably *fluorine* (and possibly vanadium, tin, and/or others) – have practical interest as agents which help to combat tooth decay (see Chapter 18).

Besides occurring in the amino acids cystine and methionine, *sulfur* is a component of at least two other nutritionally important food substances, thiamine and biotin, which will be considered in later chapters. From the sulfur-containing amino acids are formed other sulfur compounds which play important roles in body processes, among them: β-mercaptoethylamine, one moiety of coenzyme A; and the recently discovered thioctic or α-lipoic acid, which also plays a part in certain enzyme systems controlling metabolic changes in the body (see Olson, 1954).

The sulfur consumed as various organic constituents of the diet is practically all converted in the metabolic breakdown processes to sulfuric acid. A part of the sulfate so formed is incorporated into bony structures during growth, as chondroitin sulfate, a prominent component of cartilage; but the remainder must be excreted chiefly as neutral inorganic sulfates and so, as we shall see, presents a major problem in the acid-base economy.

Thus, in the case of sulfur, what entered the body as a neutral element has become a strong "fixed acid" through the normal oxidation process of our metabolism. Even a moderate protein intake results in the formation of around two grams of sulfuric acid (sulfate ion) in the body every

[2] See B. L. Vallee, Letter to the Editor, *Nutrition Reviews*, vol. 14, page 95, 1956.

[3] Among them, xanthine oxidase, aldehyde oxidase, and the cytochrome system.

day. While the weight of carbonic acid simultaneously produced is many times greater, it leaves the body through the lungs without presenting the same sort of elimination problem as does the end product of the sulfur metabolism. This is discussed further under acid-base balance below.

Organic Acids

Except for the discussion of fatty acids in connection with fats and lipoids, the organic acids which occur in foods, and some of which also occur to an important extent in the body, were only very briefly mentioned in Chapter 2. It seems more advantageous to consider them at the present point because of their interrelations with the mineral metabolism, and particularly the part that some of them play in the phenomena of acid-base balance or the maintenance of the body's essential neutrality.

Perhaps we should first define the categories of acids with which the body has to deal from this point of view. Organic chemistry is, in the main, the same as the chemistry of carbon compounds; but we do not ordinarily consider carbonic acid as an organic acid. By *organic acid* (or organic acid radicle) we mean one which contains carbon and which can be burned. But of those which burn readily when heated in air, some do and some do not undergo ready and fairly complete oxidation in the body; and this distinction has an important bearing upon the problem of acid-base balance in foods and nutrition.

The present writers consider it an open question whether study of acid-base balance as in the following section beginning on page 129—belongs strictly to the Essentials of Nutrition, or not. Those who do study it will do well to bear in mind four categories of acids: (1) organic acids readily oxidizable in the body; (2) organic acids not readily oxidizable in the body; (3) carbonic acid, "mineral" but "weak" and readily volatilized through the lungs; (4) fixed mineral acids, presenting a quite different elimination-problem from carbonic acid.

Before proceeding to the phenomena of acid-base balance, some of the organic acids deserve a few words on their own merits as nutrients.

Although the three major organic foodstuffs are practically

neutral, certain foods as they are eaten are frankly acid, owing to the presence of substantial amounts of organic acids, such as citric, malic, lactic, and tartaric.

Of these, citric and malic acids are the most widely distributed, one or both of them occurring in appreciable concentration in practically all vegetables, and still more abundantly in fruits. Milk also contains citric acid to the extent of about 1.5 grams per liter.

The body seems able to burn as fuel practically all of the citric acid any diet is likely to contain, forming carbon dioxide and water to be disposed of along with the same products from the metabolism of other organic foodstuffs. Less is known of the fate of malic acid in the human body; but it is believed to be quite readily utilized.

So far as is known, tartaric acid occurs abundantly only in grapes. When these are eaten, the tartrates which they contain appear to be largely broken down by the bacteria in the digestive tract. It is said that only a small fraction, if any, of the tartaric acid is absorbed from the intestines; and that the body tissues have almost no ability to destroy the tartrate which does reach them. Whether, and to what extent, the eating of grapes presents the body with a problem of acid disposal will thus depend upon the degree to which the tartrate radicles are absorbed; and this apparently differs largely among individuals.

Lactic acid is prominent in buttermilk and in sauerkraut and certain other fermented foods.

Acetic acid is found in vinegar, and in pickles and other foods prepared with it.

A substance known as quinic acid is present (along with other organic acids) in plums, prunes, and cranberries. The body cannot carry the breakdown of this substance completely to carbon dioxide and water, but another organic acid, hippuric acid, is the end-product.

Oxalic acid occurs in small amounts in many fruits and vegetables, and to an important extent in spinach, New Zealand spinach, Swiss chard, beet tops, lambsquarters, poke, purslane, and rhubarb. However, the nutritional significance of this organic acid is not primarily one of acid-base effect but attaches rather to its property of combining with dietary calcium to form an insoluble salt which the body cannot absorb and so cannot utilize. The effective loss of food calcium brought about by certain oxalate-rich vegetables will

be again considered in the next chapter, as logically influencing our selection of foods.

Acid-Base Balance in the Body

The normal condition of the blood, and, so far as we know, of the tissues generally, is very nearly neutral. Neither a distinctly acid nor a strongly alkaline condition of the blood, or of the system generally, is compatible with health or even with life. The maintenance of the normal condition of approximate neutrality is what one usually has in mind when one speaks of the problem or the phenomena of acid-base balance in the body.

Acidosis is a technical term in medicine, now used in a very special and restricted sense. It designates that condition in which the oxidation of fatty acids in the body, instead of proceeding completely to carbon dioxide and water, halts at an intermediate stage with the formation of acetone, aceto-acetic acid, and beta-hydroxybutyric acid as end-products. Any discussion of this highly special problem of acidosis belongs to medicine and not to the normal nutritional problem or phenomenon of acid-base balance.

Acid-base balance in normal nutrition has to do with the disposal of the acid-forming and base-forming elements in such manner as to maintain a general condition of approximate neutrality within the body. The more precise definition, the limits of variation, and an explanation of the "chemical mechanism" by which the nearly constant condition of approximate neutrality is maintained, are necessarily somewhat technical and involve a more chemical approach than that of the present text.

Carbohydrates and fats when normally oxidized in the body yield carbon dioxide which is eliminated through the lungs by a physiochemical process of marvelous efficiency and great theoretical interest to the student of general physiology; but which from the viewpoint of our present study may be said to be so nearly automatic as not to constitute a responsibility of nutrition in the ordinary sense.

Proteins of course yield carbon dioxide too; but the more distinctive end-products of their metabolism are the nitrogen compounds, from all the amino acids, and the sulfuric acid (sulfate ions) from those which contain sulfur. It is the formation of a considerable amount of such a strong, fixed (non-volatile), acid as sulfuric, from the previously neutral sulfur of food protein, which makes some students of nutrition (including some, but probably not most, physicians) feel that there is an acid-base problem which lies within the distinctly nutritional responsibility of food selection.

In this sense, it is a problem involving both the proteins and the salts or ash constituents of the food.

Some of the proteins contain phosphorus and thus yield phosphoric, as well as sulfuric, acid in metabolism; while many foods contain significant amounts of other organic compounds of phosphorus and also of phosphoric acid radicles (phosphate ions) in the form of mineral or inorganic salts.

Chlorine completes the list of the three *fixed-acid forming* elements which enter in significant amounts into the problem; but here the acid radicle is entirely pre-formed in the food and as it enters the body is usually accompanied by its full equivalent of base.

To balance the (fixed-) "acid-forming" elements (sulfur, phosphorus, and chlorine) the food furnishes significant (though quite variable) amounts of four "base-forming" elements: sodium, potassium, calcium, and magnesium. Also we find that a variable proportion of the nitrogen from protein metabolism leaves the body as ammonium salts of fixed acids (often called "ammonia"), indicating that a part of the "waste" nitrogen from protein metabolism may on occasion help out the base-forming elements in the maintenance of body neutrality. Most of the nitrogen, however, is excreted as the essentially neutral substance, urea.

In normal nutrition the "problem" of acid-base balance is chiefly that of elimination of surplus fixed acid, especially that formed from the oxidation of the sulfur of the food protein. This surplus fixed acid is taken care of chiefly in two ways: (1) by elimination of nitrogen as ammonium salt as just explained; and (2) by the secretion of a more acid urine, which usually means a larger proportion of *acid* phosphate in the urine. In case the surplus of fixed acid is small or transient, a shifting of the proportions between mono- (primary) and di- (secondary) phosphate may suffice; but beyond this, the increased excretion of primary phosphate may involve increased excretion of total phosphate necessarily carrying with it some fixed base and thus tending to deplete the body's *alkaline reserve*.

As a precaution against such depletion, it is sometimes thought worth while to balance the foods in which (fixed) acid-forming elements predominate ("acid-forming foods") by including in the diet corresponding proportions of "base-forming" foods which contain more than enough of fixed base-forming elements to neutralize the fixed acid formed by the metabolism of these foods.

Meats and fish, eggs, and grain products are acid-forming foods in the sense here explained. Their acid-forming character cannot be demonstrated by burning in air and testing the ash, because the surplus sulfuric acid is driven off by such heating in air.

Table 14 shows the relative acid-forming properties of some such foods per 100 grams and per 100 Calories.

Table salt and foods which are practically without protein or natural ash constituents may be regarded as neutral in metabolism.

TABLE 14. *A Few of the Foods in Which Acid-forming Elements Predominate*

Food (edible portion)	*Approximate potential acidity (cc. normal acid)*	
	per 100 grams	*per 100 Calories*
Beef, round steak	15	8
Eggs	15	9
Oysters	8	10
Oatmeal	13	3
Rice	8	2
Wheat, entire	11	3
White bread	5	2

TABLE 15. *A Few of the Foods in Which Base-forming Elements Predominate*

Food (edible portion)	*Approximate potential reserve alkalinity (cc. normal alkali)*	
	per 100 grams	*per 100 Calories*
Apple	4	7
Banana	8	9
Cantaloupe	6	30
Carrot	10	24
Kale	10	25
Milk	2	3
Orange (or juice)	5	11
Pear	3	5
Potato	9	12
Tomato (or juice)	5	25
Watermelon	4	14

Base-forming elements predominate slightly in milk and to a more pronounced degree in most fruits and vegetables, of which some typical illustrations are given in Table 15. Foods such as the citrus fruits are *acid as eaten but base-forming or "on the alkaline side" in metabolism* because their organic acid radicles (whether present as free acid or as acid salt) are largely or completely burned in the normal oxidation processes of the body.

At present it should be frankly recognized that there are differences of opinion as to the significance of the acid-base balance of foods among those who are such able and thoughtful students of the subject as to entitle their views to respect. Some hold the regulatory "mechanism" of the normal body to be so efficient that the balance of acid-forming and base-forming elements in the food is of no consequence to nutrition and health. Others, agreeing that the blood maintains its neutrality with great efficiency, still think that the body is better off when it is not forced to excrete a markedly acid urine. We may doubtless accept the evidence of experience that many people have been benefited by giving a higher place to fruits and succulent vegetables in their daily dietaries; but how the credit for the benefit is to be distributed between base-forming elements and vitamins is as yet an open question. In our opinion more of the newest knowledge of nutrition is needed before anyone can confidently attempt a conclusive weighing of the evidence.

EXERCISES

1. Put about 10 grams of grapefruit juice in a platinum or silica dish. Show that the juice is acid. Evaporate it to dryness and burn it to ash. Show that the ash is alkaline.

2. Explain why the typical "acid-forming" foods do *not* yield a correspondingly acid ash when burned in the air. What acid, produced in significant amounts in metabolism, is a "fixed acid" in the body, but is volatilized when heated in an open dish?

3. With the facilities available to you, can you show that the urine is rendered less acid by eating oranges or grapefruit, more acid by eating lean meat or eggs?

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8

PHOSPHORUS AND CALCIUM

Occurrence and Functions of Phosphorus

Phosphorus occurs in the body as a constituent of many of its materials, and functions in many nutritional processes. A glance at its occurrence in nature is of interest as introducing us to "the phosphorus problem" of nutrition and of food supply.

The late Dr. F. W. Clarke, long the chief chemist of the United States Geological Survey, estimated that phosphorus constitutes 0.11 per cent of the crust of the earth; but it is rather unevenly distributed, and largely locked up in the form of phosphate rocks some of which are very resistant to weathering and so yield their phosphates but slowly to the soil. Hence phosphorus is one of the elements in which soils are most often poor, relative to the needs of the plants which grow upon them. For about eighty years the attitude of science had been that the phosphate fertilization of the soil may be expected to result in larger crops, rather than crops containing significantly higher percentages of phosphorus.

Within the last fifty years, however, it has been found, first in South Africa and thereafter in several other parts of the world, that phosphorus-poor soils may produce phosphorus-poor forage with resulting tendency to shortage of phosphorus in the nutrition of cattle obliged to subsist on such pastures.

The general tendency in plants is toward a relative concentration of calcium in the leaves and of phosphorus in the seeds. Hence pasture-plants become poorer in phosphorus in the late summer and autumn when the seeds have fallen to the ground. And in general, there is relatively more danger of shortage of phosphorus in the leaf diet of grazing cattle; and of calcium deficiency in the dietaries of people who eat relatively little of leaf foods and relatively large amounts of seeds and their milling- and bakery-products. However,

t would not be scientifically justifiable to ignore the phosphorus problem in human nutrition. (At the "rickets age" phosphorus may be the limiting factor in the body's development.)

Phosphorus is an essential constituent of every known tissue and cell in the body. Although probably nearly 90 per cent of the total phosphorus of the adult body is in the skeletal system, yet the amount and the wide distribution of the phosphorus compounds of the tissues including the body fluids, give them a position in the active metabolism of the body fairly analogous to that of the proteins, although the total amounts involved are not so large.

Amount of Phosphorus Required

With phosphorus functioning in so many ways in the body, considerable interest attaches to the question of the amount which the body must receive daily from the food in order to meet the needs of replacement of the phosphorus spent in connection with these functions.

From the data of about one hundred studies, each of some days' duration, in which the quantitative balance of intake and output of phosphorus was determined in a manner analogous to the nitrogen-balance experiments described in Chapter 6, an average of 0.88 gram of phosphorus per man per day was found to be required for the maintenance of healthy adults in nutritional equilibrium. For much the same reasons as with protein, it is customary to add fifty per cent when setting a "dietary standard."

The National Research Council's explanation of the absence of a column of figures for phosphorus in its table of Recommended Allowances is as follows: "The evidence indicates that the phosphorus allowances should be at least equal to those for calcium in the diets of children and of women during the latter part of pregnancy and during lactation. For other adults the phosphorus allowances should be approximately one and one-half times those for calcium. When the calories are obtained largely from cereals, computation of the total phosphorus intake may be misleading because phytin phosphorus may be poorly utilized unless the supply of vitamin D is adequate [see page 146 below]. In general, it is safe to assume that if the calcium and protein needs are met through common foods, the phosphorus requirement also will be covered,

because the common foods richest in calcium and protein are also the best sources of phosphorus." (National Research Council Publication No. 302, *Recommended Dietary Allowances*, revised 1953, page 24.)

Calcium Requirements for Adult Maintenance

We have seen in Chapter 6 how balance-experiments with graded intakes are used in studies of protein (and amino acid) requirements: and have indicated briefly above that analogous studies of the phosphorus balance serve to indicate phosphorus requirements. In a similar way, calcium-balance experiments may serve for the finding of minimal-adequate calcium needs. But in the case of calcium it is especially important to distinguish between the merely minimal-adequate intakes and those which yield *best* results in the long run of a lifetime.

Up to 1920 there had been published about one hundred calcium balance experiments with healthy human adults, in which (in the light of the knowledge of that time) it was thought that the output approximated the "rock bottom" level of actual need for normal minimal-adequate maintenance. The mean (arithmetical average) of the findings thus brought together in 1920 was 0.45 gram as an estimate of the lowest possible maintenance level for the average normal man. And, obviously, in a normal adult population, about one-half of the people would have their needs covered by such an average figure, and about one-half would not. For a tentative allowance intended to meet the needs of practically all normal cases, it was (in 1920) suggested that the "dietary standard" be set fifty per cent higher than the above "rock bottom" average, i.e., at 0.68 gram per day for adult maintenance. This served as a tentative "standard" for about twenty years.

By the time the National Research Council was drawing up its Recommended Allowances in 1941, however, the view had developed that the "rock bottom" need for calcium maintenance was somewhat higher than the 0.45 gram estimate of 1920, and the allowance was correspondingly set at 0.8 gram of calcium a day for the normal maintenance of either man or woman, regardless of muscular activity. In the discussion accompanying the recommendations, the allowance of as much calcium for women as for men, not-

withstanding the higher body weight of the latter, was explained as a "free-hand" recognition of the desirability of generosity of calcium intake in anticipation of the extra demands of pregnancy and lactation on a considerable fraction of the females of the population.

The allowance was subsequently raised to 1.0 gram per day in 1948, in consideration of newer data and revised methods of interpreting the balance data which tended to raise further the "rock bottom" minimum and to emphasize the great variations between individuals; and in recognition of evidence from animal experimentation of long-term beneficial effects of a generous calcium intake.

In 1953, the Recommended Allowance for adult maintenance was again revised, this time downward to 0.8 gram per day. Some of the considerations which influenced this change have been reviewed by Ohlson (1955). Prominent among these is the growing view that man has a capacity of adaptation to lowered intakes of calcium, so that, after a longer or shorter period of habituation, equilibrium can be maintained on intakes of the order of 0.5 or 0.6 gram per day. (See Hegsted, *et al.*, 1952; Nicolaysen, *et al.*, 1953; Hansard and Plumlee, 1954.) Such considerations may indeed justify a downward revision of what can be regarded as a minimum-adequate level of intake for the adult, but it still remains a matter of scientific discrimination what level of intake will provide for optimal nutrition in the long run of the entire life span. Some of the evidence favoring a more liberal calcium intake where this higher hope of optimal nutrition is the objective, is summarized below in the section, "Significance of Long-term Liberality of Food Calcium."

Calcium and Phosphorus in Growth and Development

The High Calcium Needs of Infants and Children. Flexibility of the body at birth is an obviously advantageous property and is well fixed in our species as well as in several others. But flexible bones must mean skeletal structures in a less calcified condition than in the normal adult. Thus we are all born calcium-poor; and normal growth and development call for a marked increase not only

in the amount but also in the percentage of calcium in the body. The same is true, in less degree, of phosphorus.

The quantitative relations have been determined most fully and accurately in the case of the rat, where representative individuals of different ages can be taken in large numbers from well controlled colonies, and the entire body subjected to chemical analysis. Here it was found that the growth and development of the body to normal adult status involved a 75-fold increase of body weight over that at birth; an increase of 150-fold in the amount of phosphorus, and of 340-fold in the amount of calcium, which was contained in the body at birth.

The quantitative relationships are less extreme in the case of the human being which is born with something like one-twentieth of its adult weight and with bones correspondingly more calcified than those of the new-born rat.

The stage of skeletal development which the rat shows at birth is that of before-birth in a normal baby, and the newborn baby's skeleton is perhaps comparable in its stage of development to that of a rat about two weeks old. Still, the normal development of the baby involves not only a great deal of growth, but also and at the same time a great deal of hardening, of its bones.

Thus during growth and bodily development there is a relatively much accentuated need for calcium as compared with the needs for tissue building materials of other kinds.

The inevitable fact of being born calcium-poor is to be regarded as advantageous to the event of birth itself, but as a nutritional handicap thereafter. To enable the growing body to overcome this handicap without undue delay, to build a good skeletal framework and a sound set of teeth notwithstanding the fact that it started life under the handicap of a low calcium content, requires a food supply richer in calcium than many people find easy to realize.

Thus there is a very real "calcium problem" in human nutrition; and not only in infancy but throughout the period of rapid growth and development. Todd and his associates in their anatomical studies found a large proportion of skeletons subnormally calcified; Jeans and Stearns found that children differ markedly in the efficiency with which they utilize food calcium; and Leitch, holding with Todd and with Jeans that the optimally developed skeleton is considerably more highly calcified than has hitherto been realized,

has estimated that standards for calcium intakes and retentions should be higher than in the past.

Even among investigators who have given special attention to the calcium retentions of growing children, there are still differences of interpretation. One regards the finding of a relatively high retention as evidence of good practice in feeding; another, as evidence that calcification had previously been abnormally retarded. We have endeavored to exclude cases of the latter kind from the averages which appear on the last line of Table 16; but some critics may still regard these estimates as representing a higher level of retention than can be sustained throughout the first nine years of life.

TABLE 16. *Different Estimates of Normal Retention of Calcium During Growth and Development of the Human Body: Retentions in Milligrams per Day*

Age:	*1st year*	*2nd year*	*3rd year*	*4th year*	*5–9 years*	*10–15 years*	*16–22 years*
Shohl's average "from the literature" (adapted)	163	110	90	68	136	190	65
Macy's average (adapted) probably mainly of more recent data	189	276	276	180	220	260	32
An average of recent data compiled by the present writers	220	235	286	246	238	192	?

The Recommended Daily Allowances of the National Research Council provide 1.0 gram of calcium for children from 10 months to 10 years; 1.2 gram for ages 10 to 12; 1.3 gram for girls 13 to 20; and 1.4 gram for boys 13 to 20.

Mitchell, Outhouse, and their coworkers at the University of Illinois, under conditions tending to minimal estimates of normal utilization, find that growing children retain an average of 20 per cent of the calcium they receive in their food. This, with the Recommended Allowance of 1.0 gram of food calcium a day, would mean the retention of 73 grams of calcium per year. Allowing for 20 grams of calcium in the body at birth, and for average growth in body weight, this would result in the body containing about 1.95

per cent of calcium at the age of 4; and a little over 2 per cent at the age of 9 years. Whether the body thus early equipped with a good framework will thereafter continue to maintain its higher percentage of calcium is still an open question.

Allowances for Pregnancy and Lactation. As mentioned above, relatively more calcification occurs before birth in the child than in the rat. What the rat mother does in supplying her offspring is done predominantly during the suckling period, whereas the human offspring makes heavy demands upon its mother for calcium not only in lactation but in the latter part of pregnancy also. The calcium requirement of human embryonic development must obviously be met through the mother, and is a matter of concern to her as well as to the baby. The National Research Council has therefore consistently recommended a liberal calcium allowance for pregnancy (1.5 gram per day during the last three months); and also during lactation so long as the baby is getting most of his nourishment by breast-feeding (2.0 gram per day).

Calcium Needs of the Elderly

Loss of calcium salts from the bones is commonly noted in middle-aged and elderly people. Dr. F. J. Stare, speaking at the 1943 Conference on Nutrition in Relation to Public Health, said of his hospital experience: "It was a surprise to me to see that the majority of x-ray studies of adults past the age of 45 to 50 years showed considerable demineralization of bone." Frequently, the loss proceeds to the point of frank *osteoporosis*. It is not clear to what extent demineralization of the bone is physiological (i.e., a "natural" consequence of aging) and to what extent it is the result of inadequate nutrition. But, without denying that endocrine and other factors may play a part, it would appear that much of the calcium loss can be prevented or even replaced by a liberal intake of calcium in an otherwise well balanced diet. Vinther-Paulsen studied the incidence of osteoporosis in patients 68 to 96 years old and found that 74 per cent of the group with intakes of calcium less than 0.5 gram showed osteoporosis of the spine; 14 per cent with intakes between 0.5 and 0.8 gram showed spinal changes; and no person with an intake of calcium of more than 0.8 gram per day had bony changes demonstrable by x-ray.

There is evidence from long-term experiments with animals, ıat calcium is one factor in the improved nutritional wellbeing vhereby the advent of "old age" may be deferred and its penalties ıinimized. There seems every reason to recommend that the cal-ium intake of the elderly be as liberal as in the prime of life.

Selection of Foods to Provide Calcium and Phosphorus

The calcium and phosphorus of the food have come, of course, ıltimately from the soil (and the "ground waters" contained in it). Of late, there has been a tendency in some quarters to emphasize the effect of soil and fertilizer upon the percentages of mineral elements in the resulting crops. Study of such variations is of fundamental importance, and the findings, when established and understood, may be hoped ultimately to improve the nutritive quality of certain foods as they reach the market. Meanwhile, averages of analyses of foods from various sources, like those of Table 17 herewith and Table 47 in the Appendix, are serviceable for the general purposes which users of this book presumably have in view.

Table 17 shows the calcium and phosphorus contents of a few typical foods of both animal and vegetable origin, expressed in milligrams of calcium per 100 grams of the edible portion of the food. Data for other foods may be found in Table 47 in the Appendix and in *Agriculture Handbook No.* 8 of the U.S. Department of Agriculture.

Milk in its various forms, and such other dairy products as contain the mineral elements of milk, are the principal sources of calcium in such diets as are common in this country. In the food supply of the nation as a whole, dairy products provide about two-thirds of the total calcium.

Plant products may also contribute important amounts.

Both the calcium and the phosphorus contents of the *edible roots* are usually between 30 and 50 milligrams per 100 grams. The starchy potato tuber contains a similar amount of phosphorus, but distinctly less calcium.

In general, the *bulbs, stems,* and *twigs* are similar in calcium and phosphorus content to the roots, while *leaves* are richer in calcium, and *flowers* and *seeds* are richer in phosphorus. Analyses of the

TABLE 17. *Calcium and Phosphorus in the Edible Portion of Typical Foods: Milligrams per 100 Grams*

Food	*Calcium*	*Phosphorus*
Foods of animal origin		
Beef, lean muscle	11	180
Cheese, Cheddar type	725	495
cottage	96	189
Eggs	54	210
Milk, whole, fluid	118	93
dry, non-fat	1300	1030
Salmon, including bones	259	344
Sardines	386	586
Tuna fish	8	351
Grain products		
Oatmeal	53	405
Whole wheat flour	41	372
White flour	16	87
White bread, 2% milk solids	65	81
4% milk solids	79	92
6% milk solids	92	101
Fruits and vegetables		
Apples	6	10
Asparagus	21	62
Broccoli, flowerbud	89	111
leaves	318	67
twigs	73	38
Carrots	39	37
Kale	225	62
Lettuce, headed	22	25
loose-leaf	62	20
Oranges	33	23
Potatoes	11	56
Tomatoes	11	27

edible twigs, the flowerbuds, and the leaves of the same samples of broccoli resulted as shown in Table 17.

Green leaves, in the diets of people who appreciate them, rank second only to milk and its products as source of calcium. Those of the loose-leaf varieties of cabbage and lettuce contain much more calcium than the relatively colorless inner leaves of the headed varieties, though the phosphorus contents are about the same. Spinach and other leaf foods of "the goosefoot family" (*Cheno-*

podiaceae, including beet greens, chard, lambsquarters, and spinach) have been found to contain relatively large amounts of oxalic acid which interfere with the utilization of calcium. The *Compositae* (including dandelion, endive, escarole, and lettuce) and the *Cruciferae* (including broccoli, Brussels sprouts, cabbage, collards, kale, kohlrabi, mustard greens, turnip greens, and watercress) contain only insignificant amounts of oxalic acid and are correspondingly better sources of calcium. These statements are based on determinations of oxalic acid in many specimens and by several investigators, while the direct experimentation upon calcium utilization has been chiefly with (1) spinach, (2) loose-leaf lettuce, and (3) kale and Chinese cabbage, as respectively representing the three botanical families whose leaves are most used as human food.

Upon bringing together the evidence of several investigations it is seen to be established by well-controlled experiments that the calcium of cabbage, collards, kale, leeks, lettuce, rutabaga leaves, tendergreen, and turnip tops, like that of milk, is well utilized in nutrition; while that of spinach, beet greens, and New Zealand spinach is utilized very poorly if at all.

Utilization of calcium and phosphorus from grain products: the phytic acid problem. A wide variety of plant materials contain a significant fraction of their phosphorus in the form of *phytic acid*, the hexaphosphate of the vitamin inositol. It is particularly prominent in whole cereal grains where 40 to 90 per cent of the phosphorus may be in this form. Most of the phytic acid in grains is present in the outer bran layers, and so is largely removed in most highly milled cereal products; though polished rice is said to contain considerable phytic phosphorus. Owing to the presence of phytases in some grains, phytate compounds are broken down during germination and even, to a certain extent, under some conditions of industrial processing.

The wide occurrence of phytic acid is of interest and concern to the nutritionist from two points of view: can the body make effective use of the phosphorus so supplied to the diet, and does the phytic acid, which is known to form complexes with certain ions such as calcium and iron, interfere with the body's absorption and utilization of these mineral elements?

According to present knowledge, the phytic acid must be broken down in digestion to phosphate and inositol before the phosphate

can be absorbed and utilized.[1] Many studies, notably those of the late Sir Edward Mellanby and of the group at the University of Wisconsin, have shown that under conditions in which phosphorus is the limiting factor of the diet, rations containing large amounts of cereal grains are inferior to diets containing the same amount of phosphorus but in which this element is supplied in the form of inorganic phosphates; an effect which can be attributed to the presence in cereals of a large fraction of the phosphorus as phytic acid, which is incompletely broken down and utilized in digestion. Later studies showed that vitamin D increases the utilization of the phytate phosphorus, at least partly through an increase in the amount of *phytase* (phytic acid-splitting enzyme) in the intestines. However, even with vitamin D, the phytate phosphorus appears to be less completely available than other forms of dietary phosphorus (Steenbock, *et al.*, 1953). This unavailability of a significant fraction of the phosphorus of some cereals could be a matter of practical concern in human nutrition at the state of development where phosphorus may be a limiting factor in development, as at the "rickets age," and suggests the importance at this time of including ample phosphorus from other sources as well.

However, to the extent that, for the majority of the human population, calcium is more apt than phosphorus to be in critically short supply, greater concern attaches to the possible effect of dietary phytate in preventing utilization of calcium. That phytates can indeed decrease the net absorption of calcium in human beings has been shown both in experiments where sodium phytate was added to the diet and in experiments comparing the utilization of calcium on cereal diets naturally rich in phytates (e.g., from oatmeal or whole wheat) and on those from which most of the phytate has been removed by milling (e.g., farina and white flour). In the studies of Bronner, *et al.*, (1954) using radiocalcium as a tracer, it appeared that soluble phytates added to the diet interfered with the absorption of calcium to a greater degree than corresponding amounts of naturally occurring phytate compounds in oatmeal. The amount of calcium rendered unavailable by the oatmeal amounted to about 15 milligrams on a low calcium breakfast, and no effect of

[1] In a recent (1955) review, Harris considers that "it is probable that appreciable amounts of phytic acid are hydrolyzed in the human intestinal tract."

the oatmeal was evident when the breakfast contained moderate amounts of calcium.

Reviewing the recent evidence, Harris (1955) writes: "It is clear that phytic acid is present in many of our foods and that it may interfere with mineral nutrition. The phytate problem may be serious in areas of the world where the people consume large amounts of unrefined cereals and small amounts of calcium. It is not an important problem in the United States where the people usually consume refined cereals, and generous amounts of calcium-rich foods."

Other Nutritionally Available Sources of Calcium

By making use of the suggestions of the preceding section, most readers of this book can so adjust their food budgets as to increase their dietary intakes of calcium and some other important nutrients with little if any increase in total expenditure for food. In areas where this is less easy, and in families or institutions in which it is desired to increase the calcium intake with no readjustment whatever in dietary pattern, there may be interest in nutritionally available sources of calcium other than (and additional to) natural foods.

Such a supplementary source of calcium we already have in natural drinking waters, but these vary rather widely in their calcium contents. The "hard" waters of some sections of the country contribute important amounts of utilizable calcium.

A more substantial calcium supplement can be made almost automatic, as McCollum pointed out some years ago, by mixing calcium carbonate or phosphate (or a mixture of them) into the household supply of table and cooking salt.

As already done successfully in Great Britain, calcium could be made a regular part of flour and bread enrichment.

Bones of meat animals (including birds and fish) constitute a rich source of calcium which can be brought into human nutrition in any (or more than one) of an interesting variety of ways. The simplest way is merely to masticate as much as one can of whatever bones accompany the meat, fish, and poultry to the table. Thus a Serbian professor startled his colleagues of an American faculty club by unselfconsciously eating the bones which came in his

chicken pie, according to what travelers tell us is the general custom of Eastern Europe and the Middle East. Even the most conventional of us may take advantage of the calcium which comes to us in the bones of canned fish, such as salmon and sardines. The very long stewing of meat-on-its-bone with water and corn, observed by LaFarge among the Indians of the American Southwest, doubtless brings a significant share of the bone calcium into human nutrition. The Oriental custom of preserving and cooking meat-on-the-bone with vinegar brings into human (physiological) consumption a still larger proportion of the bone calcium. The fact that even dry grinding makes the calcium of bones about as available as food calcium generally was established by the laboratory research of Drake, Jackson, Tisdall, Johnstone, and Hurst (1949). Ashes of leafy plants have been used as a supplementary source of dietary calcium. Alfalfa-ash suggests itself in this connection and could readily be had in large quantities at little cost if there were a demand for it.

In parts of the Orient the chewing of native leaves and nuts prepared with lime is reported as bringing considerable amounts of calcium into human nutrition. Even without the admixture of lime, many leaves are already fairly rich sources of calcium.

While we have only fragmentary knowledge of such incidental sources of calcium, it seems more probable that many people living on supposed calcium-poor diets get significant amounts of supplementary calcium from sources which we do not know, than that our investigations have seriously overestimated the amount of calcium which should be recommended as an allowance for the support of optimal nutritional status. People can live on smaller amounts than those of the Recommended Allowances, but probably are not then so well off in the long run of a lifetime.

Significance of Long-term Liberality of Food Calcium

As explained in Chapters 5 and 6, respectively, the continued consumption of any considerably larger amount of total food (counted in calories) than is needed for optimal growth or the maintenance of the best body weight, tends to an undesirable accumulation of surplus body fat; while a corresponding surplus consumption of protein has only a doubtfully measurable effect upon

the protein content of the body and is of questionable benefit to its health and longevity.

Surplus calcium has a different significance from either surplus calories or surplus protein, in that long-term studies show that stepwise increases of calcium intake above the minimal-adequate level tend to higher levels of positive health and an increase in the length of normal life. This finding rests, first, upon a large amount of direct human experience, in which, however, the investigator obviously cannot so control the food and the drinking-water as to make calcium the sole variable throughout whole natural life cycles; and, second, upon experiments with laboratory animals whose food habits and nutritional processes are sufficiently similar to the human and which can be, and have been, kept under complete quantitative and qualitative control throughout entire life cycles and successive generations.

In typical long-term experiments of this kind, rats of the Columbia chemical laboratory colony were fed its Diet No. 16 with and without graded additions of food calcium, the basal diet containing 0.20 per cent of calcium in the air-dry food mixture. The fact that this basal diet was adequate to all the nutritional needs of the rats (in the ordinary understanding of the word adequate) is amply shown by the fact that families are still (1956) thriving in the 82nd generation on this diet. Yet this level of calcium intake, *while adequate, was less than optimal.* For strictly parallel "lots" or experimental families, differing only in that their food contained more calcium made *better* records. Thus with 0.35 per cent calcium as compared with 0.20 per cent, there was a more efficient use of the food consumed (whether calculated on the basis of its energy value or of its protein content), with moderately increased rate of growth and adult size and distinctly earlier maturity, higher adult vitality, and increased duration of the "prime of life" or "useful" life—the period between the attainment of maturity and the onset of senility. The rats on the diet of higher calcium content also lived longer even if the comparison is made without including infant mortality. In other words the higher calcium intake increased not only the average length of life but also the *adult life expectation.*

When the diet, otherwise unchanged, was still further increased in its calcium content, the gains in wellbeing just described were again increased in measurable degree. Thus successive increases in

dietary calcium induced successive gains in positive health up to intake levels relatively much higher than what we have considered safe standards in the past.

In the particular series of experiments of which we are here speaking, the increased length of adult lives on the diet with 0.35 per cent calcium over those with 0.20 per cent, was clearly statistically significant with the males, but less so with the females; perhaps because the females receiving 0.35 per cent calcium had borne and suckled more young, and brought them to higher average weight at a standard weaning time, than had those with 0.20 per cent calcium. When, then, the females on the higher of these two calcium intake levels lived only slightly longer than those on the lower level, the question arose whether this was because females are less able than males to invest extra calcium in extra length of life, or because at the calcium intake levels of these particular experiments, these females had invested their extra calcium in more and superior offspring instead. That the latter is the correct answer has been shown by further experimentation in two quite different ways: *First*, in females kept unmated and thus having no offspring in which to invest it, the extra calcium conferred at least as much improvement in longevity as it did in the corresponding males. *Second*, it was shown in another series of experiments that with still larger allowances of dietary calcium the females were enabled *both* to rear more and sturdier offspring and to enjoy longer lives themselves.

These and many other experiments indicate that at least two to three times the minimal-adequate intake of calcium is needed for *best* long-term results. Animal experimentation cannot be expected to give us (by itself) exact quantitative knowledge of human requirements, but these comprehensive and searching animal experiments do guide our judgment and justifiably confirm our confidence in leaning to liberality of calcium allowances for people of both sexes and at all ages. This gives greatly accentuated interest and significance to the problems of the influence of nutrition upon the chemical composition and internal environment of the normal body.

Analyses of large numbers of the offspring of parallel families of laboratory animals (rats) on diets containing on the one hand a little over the minimal-adequate calcium content and on the other hand from three to four times as much, have shown that this liberal increase over a level of intake already adequate for normal health

and development results in a higher percentage of calcium in the body at a given age or size. The difference becomes measurable very early in life, is greatest during the period of most rapid growth, and is still significantly measurable in the adult. All the evidence indicates that this more rapid calcification of the skeletal system is advantageous to the nutritional wellbeing and positive health both at the time and throughout the subsequent life of the individual whose development has been thus expedited by a liberal calcium content in the family food supply.

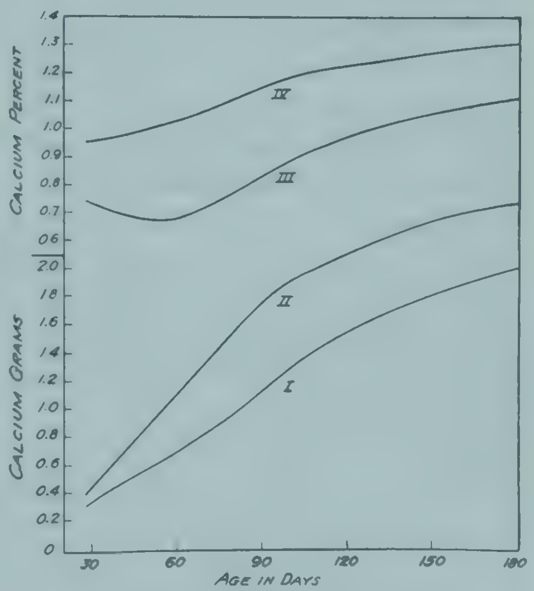

Fig. 13. Influence of the calcium content of the food on the rate of retention of calcium in the body. Average results for female rats. Curves I and II show *amounts*, while Curves III and IV show *percentages*, of calcium in the rats from the lower and higher levels of food calcium, respectively.

As illustrated by Fig. 13 for female rats, the curves for *percentages* of body calcium are different on the higher and lower intakes of food calcium. Females on the low-calcium diet show a pronounced *dip* during about the period of adolescence. (A similar, though less marked, dip is noted for males on low-calcium diet.)

This dip in the curve does not mean a negative calcium balance. These animals were increasing their amounts of body calcium but less rapidly than their body weights were increasing, so that their percentages of body calcium were decreased for a time during which they were *calcium-poor in this sense*, notwithstanding the fact that their calcium balances were positive throughout.

Further studies of this phenomenon (which doubtless has its analogue in the experience of human families which live for long

times on low-calcium diets) have been made in the Columbia chemical laboratories.

If, instead of calcium, protein, as such or as meat, is added to the basal Diet No. 16, again there is increased growth and earlier maturity but, at least in the females not all of the effects are consistently beneficial. More often than their sisters on the unsupplemented diet, the females given extra protein (on a low-calcium intake level) break down in early reproduction and lactation and thus increase the deathrate of adolescent and young adult females. And those which survive tend to show a shortening of the "prime of life" (as judged by the duration of their ability to bear young). Analysis shows that the bodies of typical females from the protein-supplemented group actually contain less calcium than those of their controls. This finding, together with other suggestions of a protein-calcium imbalance, led to a further series of experiments in which the calcium content as well as the protein content of the basal diet was enriched. This final series indicates that the hazard of extra dietary protein (at the levels and under the conditions of these experiments) is largely forestalled when the diet is sufficiently enriched in calcium at the same time as in protein. While such animal experimentation can not be expected to furnish a precise direction as to optimal levels of intake for human nutrition, it does guide our judgment as to how the emphasis may best be laid. This new evidence makes it wise to be liberal in dietary allowances of calcium, and especially it indicates that dietaries which are generous in protein should be of liberal calcium content also.

As previously noted, 99 per cent or more of the calcium retained by the body takes the form of the relatively resistant bone and tooth minerals of the skeletal system. The question therefore arises whether an increased amount of such sparingly soluble calcium salt in the body's hard structures will significantly influence the concentration of calcium in the soft tissues and body fluids. Here it is of great interest that different investigators, using different species, have consistently found that increased retention or storage of calcium in the body involves increased development of the bone *trabeculae*. These are delicate crystals of calcium salts which grow from the inner surfaces of the ends of the bones, forming, when abundant, a meshwork of readily available calcium-containing material in the normal bone cavities, especially near their ends. As the

walls of the bones are at their ends so porous and vascular as to constitute an important part of the path of the circulating blood, the nutritionally induced differences of trabecular development, as illustrated in Fig. 14, result in large differences in the surface area of calcium-containing material with which the blood comes in contact in the course of its circulation. Thus the larger the store of body calcium and the development of the bone trabeculae the more steadily is the *full* normal concentration of calcium in the blood, lymph, and soft tissues maintained. This is probably of great importance (though perhaps not yet fully appreciated) because so many vicissitudes in our life processes result in small losses of calcium which temporarily lower the concentration of calcium in the

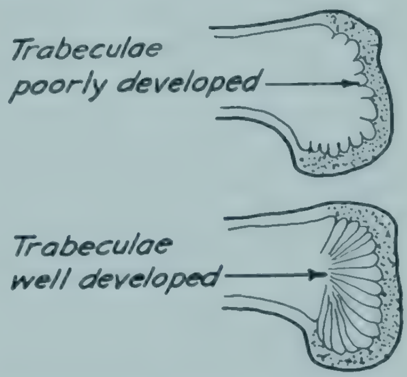

Fig. 14. Diagrammatic representation of the bone trabeculae as affected by the calcium content of the food.

blood, the full maintenance or quick restoration of which plays, as we have already seen, so essential a part in the body's self-regulatory processes. Hence, even though the body's calcium reserve is laid up in a form of such slight solubility, the more abundant the reserve the greater the calcium-saturating surface with which the circulating blood has contact and the quicker the restoration of a normal blood calcium level whenever this has been depleted in any way. Moreover, as we are only now beginning to appreciate, a normal range of blood calcium concentration which looks narrow enough from the viewpoint of current accuracy of analytical determination may still be wider than the zone of strictly *optimal* concentration. For instance, it may be said that the normal serum calcium concentration is 0.009 to 0.0115 per cent, and that the analytical determinations now current are hardly precise enough to justify attempting a more refined estimate; yet it may at the same time be true that the individual having such rich development of bone tra-

beculae as to ensure an almost constant maintenance of something near the maximum of these values may have an advantage over the individual whose blood calcium even though within the normal range is more often in the lower levels of this zone. Thus differences in a body's reserves of even such an insoluble asset as the calcium in the bones may very really and significantly influence the internal environment in the sense of the quantitative chemistry of the fluids and soft tissues of the body which directly and immediately environ its life processes.

EXERCISES

1. Calculate the amounts of phosphorus and of calcium in the dietaries planned under Exercises 2 and 3 of Chapter 5.
2. Would either more phosphorus or more calcium be desirable in either of these dietaries?
3. Tabulate the calcium content (*a*) per 100 grams, (*b*) per 100 Calories, for each of the forty foods of Exercise 2 of Chapter 4.
4. If you wish to increase the calcium content of one of the dietaries you have planned, can it better be done by changing the proportions of foods it already contains, or by substituting for one or more of these foods others which you could now select from among the forty foods of the preceding Exercise?
5. Would you substitute weight for weight or calorie for calorie, and why?
6. What fraction of your recommended dietary allowance of calcium is provided by: (*a*) one 6-ounce glass of whole milk; (*b*) a sandwich containing 1 ounce of Cheddar cheese on enriched bread (made with 4 per cent milk solids); (*c*) 100 grams of baked beans; (*d*) 100 grams kale; (*e*) one-sixth quart of ice cream.
7. Estimate the cost of 1 gram of calcium from each of the sources listed in Exercise 6.
8. Examine your list of forty foods to determine which are the 5 or 6 most economical sources of food calcium included in it. Which of these are also good sources of protein? Which are especially rich in calcium in proportion to their caloric value?

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9

IRON AND THE NUTRITION OF THE BLOOD

Occurrence and Distribution of Iron in the Body

Small as is the amount of iron in the body, its functions are very vital, as may be seen from the following five kinds of iron compounds. (1) The chromatin substance of the nucleus of every cell is an iron-protein compound. So is (2) the hemoglobin which constitutes the outstanding material of the red blood cells and has the important responsibility of carrying oxygen and assisting in the maintenance of neutrality within the body. Closely related are (3) myoglobin, or muscle hemoglobin; and (4) the cytochromes and cytochrome oxidase of active body tissues which are said (Schultze, 1947) to "mediate about 90 per cent of the energy transfer associated with the aerobic phases of tissue respiration." And also (5) there are other highly important body enzymes, such as catalases, which contain iron as an essential element.

Besides these active forms, the normally nourished body has a variable amount of stored iron, largely in the form of *ferritin*—a brown non-diffusible substance from which the iron can be released as needed for hemoglobin formation.

There is a considerable concentration of the body's iron in its blood, for while the blood usually constitutes about 7 per cent of the body weight it contains probably 55 to 60 per cent of the body iron. Iron constitutes one-third of one per cent of the hemoglobin molecule, and hemoglobin is the main solid constituent of the red blood cell. Hence any considerable shortage of iron in the body results before long in some kind or degree of anemia.

Factors Determining the Absorption of Iron from Food

Of the iron contained in the food, only a relatively small fraction is normally absorbed. It is thought that only that iron is *absorbable* which reaches the intestinal membranes in the form of ferrous ion. It is likely that some foods contain iron in the form of organic compounds from which it is only incompletely liberated in digestion—but attempts to distinguish by chemical tests the fraction which is in this sense unavailable have yielded results in some instances which are of doubtful applicability to human nutrition. Factors which would tend to reduce ferric to ferrous ion, such as a liberal simultaneous intake of vitamin C, apparently increase the fraction of the iron which is absorbable. On the other hand, substances which act to precipitate iron (such as large amounts of unabsorbed fatty acids) or to form complexes with it (phytic acid, for example), reduce the absorption of iron.

How much of the "absorbable" iron will actually be absorbed appears to depend to some degree on the body's reserve stores of iron. Thus there is some mechanism which acts to prevent the body from accumulating vast amounts of storage iron; and since the mechanisms for excretion are limited, it appears that there must be a mechanism which controls absorption.[1] When more iron is needed by the body, the amount which is absorbed may be increased, even without a change in total intake. Thus Darby (1950) states that in an iron-deficient person the absorptive process is much more efficient, and a high percentage of the ingested iron may be taken up. He also reports that studies of iron absorption in growing children indicate that "the efficiency of the absorption process parallels the need for the element. Similarly, during the latter half of pregnancy, the absorptive efficiency is greatly increased, this being the period during which the fetal iron stores are built up."

Moore (1955) has reported preliminary results of a study of

[1] A suggestion of the way in which control of absorption may be achieved has been offered by Granick (1946).

It may be said by way of caution that the control of absorption may not always be effective in the face of very large medicinal intakes of iron, and that cases of iron poisoning have been known to occur. Taking of iron salts should therefore be under the direction of a physician, not self-prescribed by the patient.

iron absorption from foods of various types in which radioactive iron had been incorporated during the normal growth or development of the food—for instance, in eggs and chicken liver and muscle meat, by injecting the radioactive isotope into the hen, and, in vegetables, by growing them in nutrient solutions to which radioiron was added. Under such conditions, the radioactive iron is assumed to exist in the foods in the same types of compounds as ordinary iron; and it should behave physiologically just as ordinary iron. Yet, due to its radioactivity this iron is "tagged" so that it can be followed into and through the body, providing a direct measure of the absorbability of the iron of the food items in question. The results so far reported show large variations, even between apparently normal individuals, so that no valid differentiation can yet be made among foods as to the absorbability of their iron. The striking finding is the low percentage of food iron which was absorbed by the normal subjects (with few exceptions, 10 per cent or less—often much less); even when taken in such small amounts as a light meal would provide. An extension of such studies may be expected to shed considerable light on the overall problem of the absorbability of iron and the related problem of dietary recommendations with respect to iron.

The Economy of Iron in the Body

Since, as we have seen, the body's iron is so largely present as hemoglobin, and this is housed in the red blood cells, the story of iron is intimately interwoven with the problems of hemoglobin formation and regeneration, the building of the red cells of the blood, and the cure and prevention of anemia.

Life-cycle of the red blood cells. The red cells (erythrocytes) of the blood are conceived as being formed in the bone marrow, circulating in the blood for an average life-time of about 4 months, and finally undergoing fragmentation, probably in the spleen, liver, and kidneys. The wearing-out of the individual red cell or corpuscle involves the breakdown of the *stroma* or containing-structure, and also of hemoglobin molecules. The main non-protein parts into which hemoglobin is broken down are: (1) the pigment, bilirubin, which is then carried to the liver and excreted in the bile, and (2) iron compounds which may be used again in the formation

of new hemoglobin. It was the interest in this reusing of the iron which gave rise to the term hemoglobin regeneration. This term gained such currency that we now sometimes meet it in scientific literature in connections which seem to indicate that the writers have used it without discrimination as to whether a real regeneration or a new formation of hemoglobin is actually involved.

Relation to copper. Copper, while not part of the hemoglobin molecule and though present in only small amounts in blood, nevertheless appears to play an important role in blood formation. In experimentally produced copper deficiency, anemia develops though the iron intake may be normal. Cartwright (1955) concludes from studies on copper-deficient swine that such animals are unable to absorb iron at the normal rate; but that the defect in hemoglobin synthesis in copper deficiency cannot be attributed solely to a failure to absorb iron; and that, for some reason, erythrocytes have only about one-fifth as long a survival time in copper-deficient as in normal animals.

Copper is thus of unquestionable importance in iron metabolism and blood formation, as well as in other ways (see Chapter 7). Adults appear to require a total of about 1 to 2 milligrams of copper per day; and infants and children about 0.05 milligram of copper for each kilogram of body weight. However, copper is so widely distributed among foods, and in amounts which appear so generous relative to human need, that most workers in the field doubt that copper is ever a factor in practical nutrition. For this reason, we give much less prominence to copper than to iron in the discussion which follows.

Anemia. The term *anemia* usually indicates a condition in which the blood is deficient (below normal) in hemoglobin, or in red corpuscles, or in both. Not all anemias are *nutritional* in the sense of being essentially conditioned by factors normally supplied in the food, and still fewer in the sense that faulty diet is the primary cause. And, of the nutritional anemias, iron deficiency is only one kind. However, since the fact that an iron-poor body tends to become anemic necessitates some consideration of anemia at this point, it is felt that a more balanced understanding will be reached if a brief panoramic picture of anemias in general is introduced, before iron-deficiency anemia is considered in connection with normal iron metabolism.

Anemia may come about when there is increased blood loss or destruction; or when there is depressed blood formation. In the latter case, the difficulty may be with the blood-forming organs (specifically the bone marrow) or it may result from a shortage in the supply to these organs of something needed in the formation of blood—and this shortage may be the result of inadequate dietary intake or of failure, for one reason or another, to utilize the factors of the food in blood building.

As nutritionists, our primary interest is in those anemias related to the inadequacy of factors normally supplied through the diet; and these we may subdivide into factors involved in the formation of hemoglobin and those involved primarily in the formation of the body or stroma of the red cell. This distinction is reflected in the blood picture which the anemia presents. One measurement used to describe the blood picture is the *color index*, which is the quotient resulting from the division of hemoglobin-in-percentage-of-the-normal by number-of-red-cells-in-percentage-of-the-normal. If there is greater proportional reduction of hemoglobin than of red blood cells, the blood is said to have a low color index, and the anemia is characterized as *hypochromic*. In the reverse condition where the number of cells has decreased more than has the hemoglobin, the color index is said to be high, and the type of anemia, *hyperchromic*. It is clear that we should expect the anemias which result from failure to form hemoglobin in normal amounts to be hypochromic anemias.

Another measurement used to characterize anemic bloods is the *mean corpuscular volume*, i.e., the volume occupied by a single red blood cell. If this volume is essentially that of the red blood cells in normal blood,[2] the blood is described as *normocytic*. If, on the average, the red blood cells are smaller than normal, the blood is described as *microcytic;* while blood characterized as *macrocytic* has blood cells of larger average size than normal.

Experimentally induced anemias. To build normal blood requires (1) an adequate supply of the building materials (iron, porphyrin, and amino acids for the hemoglobin; plus, among other things, nucleic acids for the cells themselves); and (2) right regula-

[2] The normal range for the mean corpuscular volume is 80 to 94 cubic microns; values below 80 being classified as microcytic, those above 94 as macrocytic.

tory conditions (including, for example, copper and possibly other metal ions, as well as a vast number of tissue enzyme systems of which various vitamins are essential components).

It is evident, first, that by arranging experimental conditions which limit *any one* of the vast number of factors so involved, anemia may result; and second, that there are possibilities of almost endless interrelationships among the many substances which play a part at one stage or another in blood formation.

There is thus a large volume of literature on experimental anemias, much of which has little if any bearing on conditions that are apt to be met with in human beings. The present text must concern itself largely with considerations of practical nutrition. Vilter attempted to define these in a summary (1955) of "essential nutrients in the management of hematopoietic disorder in human beings:"

It is probable that all nutrients are necessary for the formation of the normal erythrocyte, leukocyte, and platelet, and of the plasma in which these elements float. Most of these substances are so readily available that they are never limiting factors in blood formation. A select few are not so accessible to the bone marrow, cannot be synthesized by the body, and, when a deficiency occurs, may limit blood formation . . . These are iron, for hemoglobin formation, and folic acid and vitamin B_{12} for nucleic acid synthesis. It is probable that protein and particularly some of the amino acids are just as important and just as likely to be deficient when diets are inadequate or stress excessive. However, . . . little is known concerning the protein requirements for hematopoiesis in human beings.

Macrocytic anemias (pernicious anemia type). The type of anemia which was designated as pernicious at a time when it seemed peculiarly resistant, both to therapy and to scientific understanding, has now been largely conquered. Or perhaps we should rather say it has been largely solved as a scientific problem and the means for the therapeutic conquest of individual cases as they arise are now available and widely understood.

The blood picture in pernicious anemia is mainly that of deficient formation of red cells, these being usually subnormal in number, often irregularly shaped and variable in size, but with many very large cells, hence the term macrocytic anemia.

The sufferer from pernicious anemia characteristically shows deficient gastric secretion. Through the researches of Castle and others, an explanation of the specific need in pernicious anemia was suggested in terms of *two factors*, the *intrinsic* and the *extrinsic*. According to this view, the extrinsic factor is furnished by the food (in Castle's experiments by beef), and the intrinsic factor is furnished by a normal gastric juice. Originally it was thought that these two factors react to form the anti-pernicious anemia substance. With the discovery of vitamin B_{12} and the finding that vitamin B_{12} is effective alone (in controlling pernicious anemia) when injected though when fed requires simultaneous administration of intrinsic factor for efficient use, most investigators seem now to regard vitamin B_{12} as both the extrinsic factor and the anti-pernicious anemia factor; and to consider that the principal role of the intrinsic factor is somehow to facilitate the absorption of vitamin B_{12}.

Thus, in the typical case of pernicious anemia the primary fault is an abnormality of gastric juice which renders it inadequate as a source of intrinsic factor so that vitamin B_{12} (though present in the food in amounts sufficient for the normal individual) is not absorbed in effective quantities.

Interrelated with vitamin B_{12} in erythropoiesis (red blood cell formation) is another vitamin factor, folic acid or pteroylglutamic acid, which has been shown to cause prompt and dramatic improvement in the blood picture in pernicious anemia and in various other macrocytic anemias. For some of these anemias, folic acid appears to be fully effective; but it does not cure the nervous symptoms ("combined system disease") which are in some cases a part of true pernicious anemia. Thus, though both have some effect, folic acid cannot fully replace vitamin B_{12} in pernicious anemia; and, conversely, some of the other macrocytic anemias seem more responsive to folic acid than to vitamin B_{12}.

Some clue as to the interrelationship of folic acid and vitamin B_{12} in the formation of the red blood cells may be found in the evidence now accumulating that both are involved in the building of the nucleic acids, which are essential constituents of all cells; but the full picture is not clear, and there are indications that other factors also play a part.

From the practical viewpoint of pernicious anemia as it is seen

in the clinic, however, there seems now to be abundant evidence that it can be kept under full control indefinitely by periodic injections of vitamin B_{12} at the rate of about 1 microgram per day; or by feeding relatively large amounts of the vitamin with some source of intrinsic factor.

Vitamin B_{12} and folic acid will be considered further in Chapter 14.

Anemias related to iron deficiency. When there exists over a period of time a shortage of iron, whether due to poor diet, poor absorption, or some condition which intensifies the need for iron, an iron-deficiency anemia may result. In this condition, the blood is microcytic and hypochromic, i.e., the blood cells are smaller than normal and, as noted earlier, hemoglobin formation lags behind the formation of red blood cells.

Such anemias are readily detected, and usually respond to treatment with medicinal doses of iron. However, it may be repeated that *an anemia curable by iron does not necessarily owe its origin to a shortage of iron in the food.*

Since iron-deficiency anemia varies widely in frequency of occurrence with age and sex, further discussion is deferred until the specific iron needs of the various groups are considered in the sections which follow.

Conservation and Reusing of Iron in the Body. One of the amazing features of the body's economy is the efficiency with which it retains and reuses the iron which is periodically released when red blood cells break down. Thus the normal adult male will contain in his body something like 2500 milligrams of iron in the hemoglobin of the blood; of which (assuming the average life of a red blood cell to be 4 months) some 20 milligrams will daily be liberated by the breakdown of hemoglobin in normal wear-and-tear. Yet the amount of this iron which leaves the body by the principal path of excretion (the intestines) is estimated to be only 0.3 to 0.5 milligram. Thus, *where there is no loss of blood as such*, the requirement of new iron to maintain the *status quo* with respect to hemoglobin is very modest. To be sure, there are inevitably other slight losses of iron from the body, as when cells are desquamated (shed) from the skin or lining of the body tracts, when hair grows, and so on. Such losses have been extremely difficult to estimate because iron is so ubiquitous in our environment; and widely diver-

gent estimates were made on the losses that might occur in the sweat. However, Moore (1955), using radioiron, has estimated the total loss, under normal conditions, from the skin surface (in sweat plus desquamated cells) as "certainly less than 1 milligram per day and probably not more than 0.5 milligram." From his studies, he estimates the amount of body iron lost or excreted in all ways except as blood as 0.5 to 1.5 milligrams for the normal adult male. And a similar or slightly lower figure would apply to women after the menopause.

Moore holds the view that adult men and post-menopausal women seldom develop anemia simply as a result of shortage of iron in the diet or even of poor absorption of iron, stating that "it is more likely that occult, intermittent bleeding, often difficult to detect, must be present along with inadequate diet or malabsorption before severe degrees of iron deficiency develop."

The situation is different, however, in younger women.

Menstrual loss of iron. Women before the menopause have an additional loss of body iron in the menstrual flow which has been variously estimated by different investigators. Moore (1955) suggests that, for the normal woman, this amounts to something like 14 to 28 milligrams per period or an average of 0.5 to 1 milligram per day through the month.

Effect of pregnancy. During pregnancy, about 300 to 500 milligrams of iron are transferred to the infant; and, in addition, storage of iron in the body of the mother occurs in an amount which (McLester and Darby, 1952, estimate) is equivalent to the entire amount secreted in the milk during nine months of lactation. This increased need is one explanation of the iron-deficiency anemia which sometimes develops as a result of pregnancy (especially repeated pregnancy) and is one reason that some physicians, including Strauss of Harvard, have recommended the regular inclusion of supplementary iron salt in the dietaries of pregnant women.

Iron needs for growth. The newborn infant normally contains in his body something like one-seventh as much iron as the full grown adult, though he weighs only a thirtieth to a twentieth as much. The reserve store of iron with which the child is born (and which, some investigators believe, varies with the state of nutrition of the mother during pregnancy) is of utmost importance in enabling him to build the large amounts of extra hemoglobin (as well as of other

iron compounds) that are required as the body grows, especially in view of the rather low iron content of milk. Even so, it has been estimated that the amounts of iron that must be built into the body during rapid growth are so great that this reserve would be exhausted within six months after birth if no iron were absorbed from the food, or within less than a year if the only iron absorbed were a normal proportion of that in milk. One advantage of the current pediatric practice of early addition of other foods to the diet of the infant is their value in supplementing the iron intake. However, if the baby grows rapidly his body size may, and in the majority of cases does, increase somewhat faster than the total body hemoglobin, with the result that the child goes through a period of what is oddly called "physiological anemia." More clearly stated, such a child is in a normal (physiological) phase of his development and need not (should not) be considered anemic even if his hemoglobin percentage is somewhat lower than at other ages, or perhaps than in more slowly growing children of the same age. Markedly subnormal hemoglobin values, of course, require medical attention.

Premature infants have smaller iron reserves—and consequently suffer a greater hazard of iron deficiency—than full-term infants.

Figure 15 shows the estimates of Heath and Patek (1937) for the amount of iron needed at various ages to build body tissue and to replace body losses in addition to the iron which can be reused. Note that these are *not* estimates of the dietary intakes required.

It is apparent that children and young women present a quite different picture of iron need from that of adult men and older women, in that their added needs—in the one case for growth, in the other to compensate for menstrual loss and provide for pregnancy—"place them in a precarious state of iron balance, so that poor diet or poor absorption can readily lead to the production of hypochromic anemia" (Moore, 1955).

When the typical hypochromic microcytic anemia of iron deficiency is seen in women and children, the diet may be suspect; but in men and older women it is usually necessary to look farther for some cause of chronic blood loss. In any case, once iron deficiency anemia has developed, supplemental iron salts are usually required for treatment, since it is apt to be impractical to make up an accumulated shortage of iron by diet alone. Obviously, too,

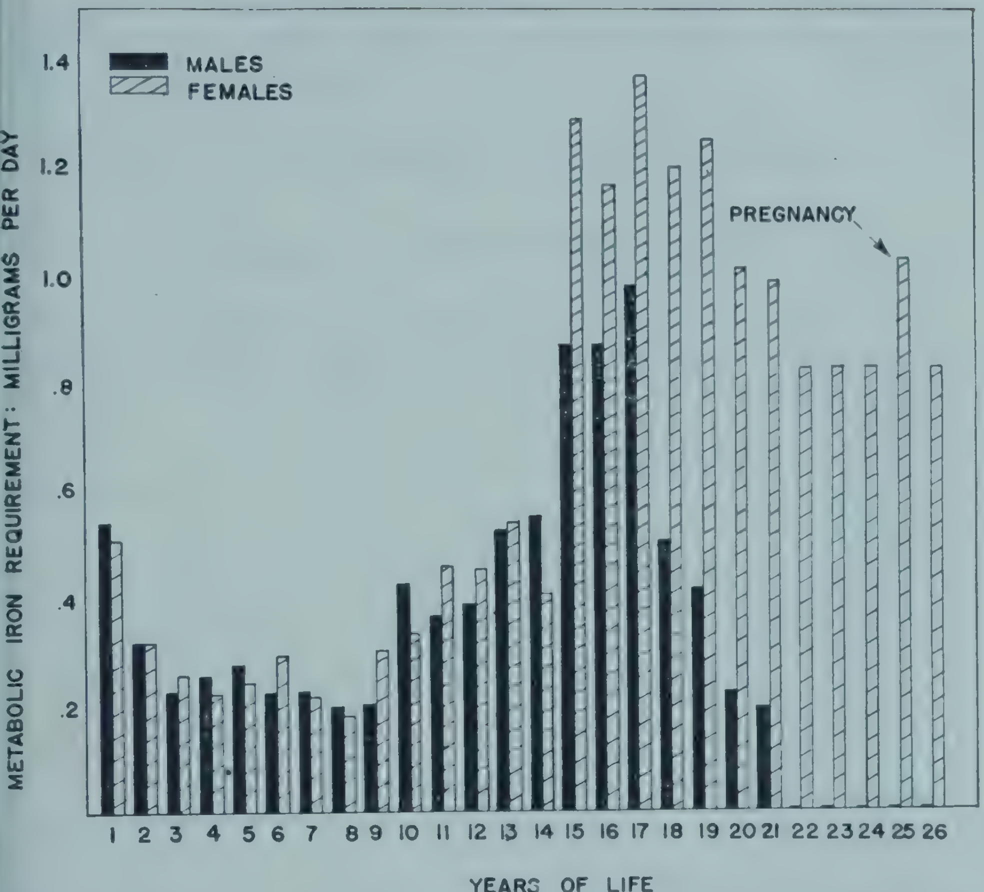

Fig. 15. The amounts of iron estimated (by Heath and Patek, 1937) to be needed at various ages to replace body losses and provide for growth of body tissue. These amounts are in addition to that iron already in the body which can be reused, and refer to available absorbed iron, not to the total dietary intake of iron. Note the great difference in this need between fully grown young men and young women.

where there is chronic abnormal blood loss steps should be taken to correct the condition.

Iron needs of the elderly. Stieglitz (1950, 1951) lays great stress on the importance of a favorable iron intake and maintenance of optimum hemoglobin levels in the elderly. He finds that habitual intakes below the recommended levels are "extremely common" in this age group and that "clinical experience reveals that a great majority of elderly persons require supplemental administration of iron salts of one form or another," for, as he emphasizes, "Anemia, even if minor, is immensely more significant in later years than in

youth, for the ability to compensate for inadequacy declines. In the presence of any circulatory handicap (arteriosclerosis, hypertension, or cardiac impairment) the quality of the circulating medium assumes a role of major importance. Optimum hemoglobin concentration should be the objective; the average does not suffice."

Recommended Allowances of Iron

The recommendations of the National Research Council's Food and Nutrition Board for dietary allowances of iron at different ages are as follows:

For adult men and (non-pregnant, non-lactating) women	12	milligrams
For women in the last trimester of pregnancy and during lactation	15	"
For children		
under 1 year	6	"
1–3 years of age	7	"
4–6	8	"
7–9	10	"
10–12	12	"
13–20	15	"

These recommendations are based largely on iron-balance experiments, considered in conjunction with the hemoglobin level of the blood. Studies by Darby and coworkers using radioactive iron have been interpreted as confirming the allowances for children 7 to 10 years old. Moore (1955) concludes from his isotopic studies of iron absorption and excretion that "healthy persons [on intakes of 12 to 15 milligrams per day] probably maintain a positive iron balance by a narrower margin than was formerly believed" and that (as quoted earlier) "the added requirements of children and young women to compensate for growth needs and menstrual flow place them in a precarious state of iron balance."

There is at the present time some divergence of expert opinion as to how generous a margin of safety the Recommended Allowances actually provide. Those who wish to secure a more liberal iron intake may easily do so, as will be seen in the next section which deals with the iron values of foods. And there is reassurance

n the government statistics which show that our national food supply provides enough iron for 17 milligrams a day for every man, woman, and child in the country.

Iron (and Copper) in Foods

Table 18 shows the approximate amounts of iron now believed to be present in the average edible portion of typical food materials,

TABLE 18. *Iron in Edible Portion of Typical Foods*

Food	Iron: Milligrams per 100 gm. food	Iron: Milligrams per 100 gm. protein	Iron: Milligrams per 2500 Calories	Food	Iron: Milligrams per 100 gm. food	Iron: Milligrams per 100 gm. protein	Iron: Milligrams per 2500 Calories
Apples	0.3	100	13	Milk, whole	0.1	3	4
Apricots	0.5	50	25	dry non-fat solids	0.6	2	4
Bananas	0.6	50	17	Molasses, medium			
Beans, dried	6.9	32	51	dark	6.0		65
Beef, lean	2.9	15	40	blackstrap	11.3		133
medium fat	2.7	15	28	Oatmeal	4.5	32	29
Bread, enriched	1.8	21	16	Oranges	0.4	44	22
unenriched	0.6	7	5	Peanut butter	1.9	7	8
Carrots	0.8	67	48	Peas, green	1.9	28	48
Chicken	1.5	7	19	Pork, medium fat	2.3	15	17
Eggs, whole	2.7	21	42	Potatoes	0.7	35	21
yolk	7.2	44	50	Prunes, dried	3.9	170	36
white	0.2	2	10	Raisins	3.3	143	31
Fish	0.7	4	22	Rice, white	0.8	10	5
Kale	2.2	56	138	Sweetpotatoes	0.7	39	14
Lamb	2.7	15	29	Tomatoes	0.6	60	75
Lettuce, headed	0.5	42	83	Wheat flour, whole	3.3	25	25
loose-leaf	1.1	92	183	white, unenriched	0.8	8	5
Liver	6.6	34	121	white, enriched	2.9	28	19

expressed: (1) in milligrams of iron per 100 grams of edible material; (2) in milligrams of iron per 100 grams of protein; and (3) in milligrams of iron per 2500 Calories.

No corresponding table is given for the copper contents of foods, for the dual reason that these are somewhat less generally estab-

lished and that present opinion holds that copper is not apt to be a factor in practical human nutrition. Those interested in learning more of the copper content of foods than is contained in the present brief discussion will find a compilation in the Seventh Edition of Sherman's *Chemistry of Food and Nutrition.*

Meats constitute a prominent source of iron in American dietaries. In ordinary muscle meats the iron exists chiefly as hemoglobin, belonging in part to the muscle cells and in part to retained blood. Since fatty tissue contains much less iron, the iron content of fat meat is much lower than that of lean, and in order to establish a useful general estimate of the amount of iron in meat it seems best to refer the iron to the protein content rather than to the gross weight of the meat. The results will still be influenced by the extent to which the blood has been either accidentally or intentionally removed from the muscle.

As Table 18 indicates, the muscle meats of beef, pork, and lamb all contain roughly 15 milligrams of iron for each 100 grams of protein. The muscle of chicken, on the other hand, provides only about half as much iron; while fish (and shellfish[3]) in general are even poorer sources of iron, with respect to their protein content. On the other hand, liver (and also kidney) is a far richer source of iron than ordinary red muscle meats, whether the comparison is made per 100 grams of meat or of protein. Liver is also extraordinarily rich in copper, containing something like half as much copper as iron.

Eggs. The edible portion of hens' eggs contains on the average about 2.7 milligrams of iron per 100 grams, practically all of it in the yolk; and approximately one-tenth as much copper. There would seem to be no room for doubt regarding the assimilation and utilization of the iron compounds of eggs, since they serve for the production of all the iron-containing substances of the blood and tissues of the newborn chick, there being no introduction of iron from without during incubation. Iron-balance experiments with young women have shown that the iron of egg is highly efficient in human nutrition also.

Milk. Fluid milk contains, on the average, about 0.1 milligram of iron and about 0.035 milligram of copper per 100 grams

[3] An exception is oysters, which are rich in iron and extraordinarily rich in copper.

amounts which are lower than most other foods even when the comparison is made in terms of milligrams of iron or copper per 100 grams of protein. As we have seen, nature provides for the iron (and apparently similarly for the copper) needs of early growth by transferring generous stores of these elements to the liver of the young mammal before birth. There are also indications from metabolism experiments that the iron of milk is readily absorbed and utilized to especially good advantage, perhaps on account of its association with a liberal (but not excessive) proportion of calcium, and with other materials of high body building value.

Fruits and fresh vegetables. These are often regarded as of low nutritive value because of their high water content and low proportions of protein and fat; but largely for this very reason they may be especially important as sources of food iron, because they can be added to the diet without replacing other foods, and without making the total calorie consumption excessive. This fact is strikingly brought out by the column of Table 18 which shows milligrams of iron per 2500 Calories. On this basis, such items as kale, lettuce (especially the loose-leaf varieties), and tomatoes appear as outstanding contributors of iron. Present transportation facilities and methods of preserving tend to equalize the cost and increase the available variety of fruits and vegetables throughout the year. It was found, in an experimental dietary study made in New York City, that a liberal use of vegetables, whole wheat bread, and the cheaper sorts of fruits resulted in a gain of 30 per cent in the iron content of the diet, while the protein, fuel value, and cost remained practically the same as in the ordinary mixed diet obtained under the same market conditions. Gillett and Rice also found that the general advance of nutrition consciousness and dietary intelligence had similarly improved the typical family food supplies of the New York City poor during the period between 1914–15 and 1928–29.

Grain products. Iron and copper occur in considerable quantity in the cereal grains, but the greater part is in the germ and outer layers, and so is rejected in the making of the "finer" mill products (though the iron is now largely restored in "enriched" flour and bread and "restored" breakfast cereals). Many years ago, Bunge demonstrated the value of the iron in the outer layers of the grain by the following experiment:

A litter of eight rats was divided into two groups of four each. One group was fed upon bread from fine flour, the other upon bread made from flour including the bran. At the end of the fifth, sixth, eighth, and ninth weeks, respectively, one rat of each group was killed, and the gain in weight, the total amount of hemoglobin, and the percentage of hemoglobin in the entire body were determined.

Here the bran-fed rats not only made a much greater general growth, but developed both a greater amount and a higher percentage of hemoglobin. There can be no doubt that the iron and other ash constituents of the outer layers of the wheat were well utilized in these cases.

More recent work of the late Dr. Mary S. Rose and her collaborators also showed clearly the good utilization of the iron of whole wheat in hemoglobin formation as tested with rats; and the high efficiency of the iron of whole wheat in human nutrition as measured in balance experiments with young women.

The enrichment program. About the start of World War II, when President Roosevelt had focussed attention on the need for better nutrition on a national scale, one means that was adopted to this end was the *enrichment* of white flour and bread by the addition to them of iron, thiamine, riboflavin, and niacin. As a wartime emergency measure, enrichment of white bread and flour was made compulsory by federal regulation; later, with the passing of the war emergency, enrichment became subject to state regulation, many of the states introducing requirements similar to the wartime federal order. Meanwhile, enrichment had spread to include (though not compulsorily) certain other items, such as breakfast foods, corn meal, macaroni, etc.

The table which follows shows how the picture has changed since just before the inauguration of enrichment, with respect to the national average per capita consumption of total iron, and the contributions made by the respective food groups to this total.

Enrichment is largely, if not solely, responsible for the 25 per cent increase in the national average per capita iron intake which has occurred since the years before World War II. Even more significant is the fact that the increase of iron intake has doubtless been proportionately much greater among the lower income groups of the population who make much larger use of grain products—and whose iron intakes were more in need of improvement.

TABLE 19. *Shift in the Total and Relative Amounts of Iron from Various Food Groups in the Average American Dietary: 1935–39 Compared with 1952* (based on Supplement for 1949 to U.S. Department of Agriculture *Miscellaneous Publication No. 691* and on *Agricultural Statistics, 1953*)

	Before enrichment program Iron: 13.6 mgm.		*After enrichment program Iron: 17.1 mgm.*	
	% of total calories	*% of total iron*	*% of total calories*	*% of total iron*
Dairy products	11.5	3.4	13.4	3.6
Eggs	2.0	8.0	2.8	9.0
Meat, poultry, fish	10.7	26.6	12.8	24.0
Vegetables and fruits	10.1	27.0	9.4	21.4
Grain products	28.0	17.9	22.8	26.6
Dried peas and beans, nuts, soya flour	2.5	7.3	2.9	7.2

The fraction of the total iron intake which was contributed by the grain products rose from less than 18 per cent in the pre-war period to 26.6 per cent in 1952; at the same time that the relative prominence of grain products in the diet, expressed as percentage of the total calories, decreased by a fifth. After grain products, the largest proportion of iron is contributed by the "meat, poultry, and fish" group, with vegetables and fruits placing third.

EXERCISES

1. Calculate the iron contents of the dietaries previously planned, and compare with your judgment of the requirements of the people to be fed.

2. What substitutions, preferably from among the forty foods previously tabulated, would enrich one of these dietaries in its iron content without any disadvantageous change in its general character or in its cost?

3. Would it be more practicable to make the proposed substitution weight for weight, or Calorie for Calorie?

4. Would it be feasible to provide as much iron as an average medicinal dosage per day through food selection without distorting the dietary or making it unduly costly?

5. Is there, in the light of present-day knowledge, any sound objection to making nutritional use of iron salts, under medical guidance, so as to be freer in planning the best use of the food money?

6. To what extent are your answers influenced by the current "enrichment" of flour and bread, and the "restoration" of breakfast cereals? And why?

7. In the local market determine the cost of the following kinds of liver: (*a* calves'; (*b*) chicken; (*c*) beef; (*d*) hog. Compare the nutritive values of these various kinds.

8. What quantity of each of the following foods will provide 12 milligrams of iron? (*a*) pork liver; (*b*) lean round steak; (*c*) dried beans; (*d*) raisins; (*e*) enriched bread; (*f*) eggs; (*g*) kale (fresh or frozen); (*h*) head lettuce. What is the cost in each case?

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10

IODINE

The Endocrine Glands and Especially the Thyroid

It has now become a concept familiar to almost everyone that the physical and mental development of an individual as well as the course and rate of his metabolic processes are controlled to a large extent by a group of organs known as the *endocrine glands* or the *glands of internal secretion.* Each of these elaborates one or more of the physiologically active, specific chemical substances, known as *hormones,* which it distributes through the blood stream to the entire body, exerting in this way a "chemical control" over even the most remote parts. When, for some reason, there is either a deficiency or an overabundance of the secretion of one of the endocrine glands, physical or metabolic abnormalities may become evident. Most of these conditions lie outside of the sphere of this book; one such manifestation, the disturbance of the thyroid gland known as simple goiter, has now been shown to be predominantly of nutritional origin and amenable to control by nutritional measures.

The *thyroid gland* is situated near the base of the neck and consists of two lobes, one to each side of the trachea ("wind-pipe"), connected by an isthmus lying across the front of the trachea. It is this structure which becomes swollen to give the familiar picture of goiter.

Goiter has been known from time immemorial: references to it are found in many of the oldest writings, and the works of the old masters attest its prevalence in their times. An Englishman who paid an extended visit to Switzerland and the adjacent parts of France and Italy in the eighteenth century, and whose letters written thence were afterward published, told of the great prevalence of goiter in certain localities. In the part of Savoy where he stayed

it was so nearly universal that anyone without goiter was said to be not a true Savoyard. Growth of the goiter was regularly expected to accompany the growth and development of the child. Thus a middle-aged man whose little granddaughter's goiter was the size of a chestnut piously hoped to live to see it as large as a pear.

Even a generation ago there were regions in this country and abroad where some measure of thyroid enlargement was discernible in a large majority of the adolescent children; and today, although recognition of its nutritional origin has made it possible to prevent almost completely the onset of the disorder, advanced goiters are a fairly common sight, at least among middle-aged and elderly persons for whom this knowledge came too late.

Establishment of the Relationship of Iodine to Goiter

It is said that for many centuries burnt sponge was a more or less popular folk remedy for goiter. Medical men, following the suggestion made by Coindet in 1820, found that painting the goiter with tincture of iodine was also frequently efficacious. As the existence of the element iodine had been discovered in burnt seaweed, Coindet postulated that iodine present in the sponge was responsible for the effectiveness of the old treatment. However, the *rationale* of both of these curative measures was fully appreciated only when Baumann, in 1895, actually found iodine in the thyroid gland. This led the way on the one hand to investigations on the natural distribution of iodine and its relation to the incidence of goiter, and on the other hand to Kendall's discovery and separation in pure form of *thyroxine*, an iodine-containing amino acid derivative secreted by the thyroid gland.

There are certain regions of the earth where—until modern preventive measures were introduced—goiter occurred so persistently and so extensively as to be called *endemic*. Notable among these districts were the Himalayan Mountain region of South Central Asia; the Alps, Pyrenees, and Carpathian Mountain regions of Europe; the Andean plateau and southeastern Brazil in South America; and the St. Lawrence and Great Lakes basin, extending through northern Ohio, Michigan, Minnesota, the Dakotas, and adjacent Canadian provinces; and the Pacific Northwest including Oregon, Washington, and British Columbia, in North America.

Examination of the soil, the drinking water, and the vegetation in these regions showed them to be relatively poor in iodine as compared with regions where goiter is not prevalent. The iodine content of the water and foods of any district seems to depend largely upon the chemical nature of the rocks and the amounts of soluble iodide which these yield in their natural weathering. In general, the leached soils deposited from the last glacial period are said to be poor in iodine. Such soils account for the low iodine content of the crops in certain regions of this continent. Furthermore, since seawater, and therefore the spray which evaporates in the air at the seashore, is relatively rich in iodine, regions near the ocean and not separated from it by high mountains receive iodide from sea-spray dust carried inland by the winds. No doubt the relative influence of rocks and sea upon the iodine content of the soil and of the drinking water varies considerably in different regions. That the resulting differences may be very great is illustrated by the finding of McClendon and his coworkers that drinking waters from different parts of the United States ranged in their content of iodine from 0.01 to 73.30 parts per 1,000,000,000—seven thousand times as much in the maximum case as in the nine minimum cases.

McClendon also showed that differences in the relative frequency of goiter among men drafted from various parts of the country for service in World War I were strikingly associated with differences in the amounts of iodine found in the drinking waters in the regions from which the recruits were drawn, goiter being very much more common in sections where the water supplied relatively little iodine.

Similarly it was found that foods produced in the regions characterized as goitrous contain in general distinctly less iodine than the same foods from the socalled non-goitrous districts. A few instances are cited in Table 20.

It is still difficult to judge how far the reports of differences in iodine contents of foods have been exaggerated by analytical errors. The example which McClendon selected for prominence in his 1939 monograph shows 111 parts per billion of iodine in the cabbage grown in eastern Minnesota where the goiter rate is 1.72 per cent, and 174 parts per billion of iodine in that grown in the western part of the same state where the goiter rate is 0.85 per

cent. Here there was presumably a maximum of scientific control, and a minimum of analytical error.

Observations such as those which have been cited, associating a low intake of iodine in food and drink by a section of the population with a high tendency to goiter, strongly suggested that the former circumstance might be the predominant factor in the causation of the latter. Further evidence of the relationship was afforded when McClendon and Williams in 1923 produced goiter experimentally in rats by a diet low in iodine, fed under conditions of laboratory control.

TABLE 20. *Iodine Contents of Foods from Goitrous and Non-Goitrous Regions*

Kind of food	*from goitrous regions*	*from non-goitrous regions*
	Iodine: parts per billion of dry matter	
Wheat	1–6	4–9
Oats	10	23–175
Carrots	2	170
Potatoes	85	226
Milk	265–322	572

Apparently, the increase in size of the gland is the result of an effort on the part of the thyroid to compensate for a shortage of iodine from which to synthesize its hormone, by increasing the number of secreting cells and the volume of fluid secreted.

Simple Goiter Prevented by Adequate Iodine Intake

The now classical experiment of Marine and Kimball demonstrated that *simple goiter,* in most if not all cases, is a *deficiency disease* resulting from inadequate dietary intake of the *nutritionally essential* mineral element *iodine* and preventable by a sufficient supply of this food factor. These investigators administered iodine systematically to as many as volunteered of the school children of Akron, Ohio, of the ages at which goiter most commonly appears. The iodine was given as sodium iodide in small doses twice weekly over a period of a month and the treatment repeated twice yearly.

The success of this preventive measure was striking. Of more than 2000 children treated, only 5 developed goiter; while, of a similar number not treated but of the same age and living in the same locality, about 500 showed thyroid enlargement during the same time. In other words, about 99 per cent of the goiters which would otherwise have developed were prevented by the simple administration of sodium iodide.

While the characterization of goiter as the most easily preventable of all diseases is a justifiable aid to memory, it should also be remembered that not all goiters are attributable to simple shortage of iodine. Conditions may arise which interfere with the normal metabolism of iodine or increase the demand for the element; so producing a relative deficiency of iodine even on an otherwise safe level of intake. Chronic infections (in some instances through contaminated drinking water) have been held responsible in some cases for such an effect. There are indications that dietary factors other than iodine deficiency may also be involved in the development of certain goiters. "Goitrogenic" or "antithyroid" compounds are known, some of which occur naturally in certain foods, notably in turnips, rutabagas, cabbage, kale, and related vegetables; and one of which was isolated and identified by Astwood, Greer, and Ettlinger (1949). Similar compounds fed to experimental animals have been shown to produce goiter; and it has been reported that feeding such substances to normal human beings inhibits the normal uptake of (radioactive) iodine (Greer and Astwood, 1948). Whether such naturally occurring substances have anything to do with the development of goiter in man under practical conditions is still an open question: though Youmans (1951), writing on the prevention of goiter, cautions "the goitrogenic action of some [vegetables], such as cabbage and related vegetables, must be considered."

The goiter problem is thus not altogether solved, and the fact that local epidemics and sporadic cases of goiter may arise from causes other than dietary lack of iodine should be frankly recognized; but should not blur the established fact that in typical regions of endemic goiter the incidence of this disease has been enormously reduced by simply supplying iodide in drinking water or in table salt. The reduction of incidence in school children by 85 per cent in three Swiss cantons and still more in the Ohio city

already referred to may presumably be taken as fairly representative of the efficacy of these methods of iodide supply.

Thus it is probably a fair generalization that nearly 99 per cent of the simple goiters of goitrous regions are attributable to iodine deficiency and are preventable by the regular use of iodide in drinking waters or (more simply) iodized salt in the households of all the people.[1]

In large cities, or over large areas, where the use of iodized salt has been advocated by health officers but without means of making it universal, subsequent surveys have shown greatly reduced goiter incidence in the families using iodized salt as compared with next door neighbors who did not.

Incidentally, it has been observed by medical schools in Great Lakes cities, that even stray dogs living largely on garbage get therefrom the benefit of the use of iodized salt in so many households that it is now quite difficult to find a stray dog with a goiter, whereas formerly the stray dogs of these cities were commonly goitrous.

Thus, according to a widely quoted statement of Dr. David Marine, goiter is "the simplest, the easiest, and the cheapest of all known diseases to prevent."

The Body's Need for Iodine

Evidently, the body has a rather definite nutritive requirement for iodine which must be met if the thyroid gland, one of the most important regulators of body processes, is to function normally. A principal function of the thyroid gland is to regulate the rate of heat production by controlling the rate of cellular oxidations. Other functions of the thyroid (as summarized by Sebrell, 1950) are "to aid in stimulation of normal growth of bones, hair, and skin; normal development of the brain; stimulation of sexual development

[1] In contrast to the now generally held view, Greenwald (1946, 1955) contends that much of the evidence purporting to show an inverse relationship between iodine intake and incidence of goiter is open to criticism on grounds of poor analytical control or for other reasons. He advances theoretical considerations that cause him to argue that endemic goiter is not due to iodine deficiency; and holds that where a preventive effect of iodized salt has been observed this was attributable to a pharmacodynamic rather than a nutritional effect.

at puberty; maintenance of a normal pregnancy; and production of an adequate milk supply during nursing."

When the supply of iodine is only moderately deficient, the thyroid gland may become enlarged to form a goiter and yet be able to provide the thyroid hormone in normal or nearly normal quantities, so that the individual continues to enjoy fairly good health. But in severe iodine deprivation, despite the compensatory enlargement and increased activity of the gland, a deficit of the

Fig. 16. The effects of administration of thyroxine on myxedema in the first young woman to be so treated. Besides the disappearance of the edema, note the increased mental alertness evident in the second photograph. (Courtesy of Dr. E. C. Kendall.)

thyroid hormone exists and may cause the profound disturbances in physical and mental wellbeing and development known as *myxedema*. The edema from which this disease takes its name is well illustrated in the accompanying Fig. 16. Another characteristic feature of this condition is a markedly lowered rate of energy metabolism, the chemical processes of the body upon which growth and function depend being stepped down, sometimes to half the normal rate. Correspondingly, the victim is exceedingly sensitive to the cold; suffers from flabbiness and weakness of the muscles, tiring easily on slight exertion; and his mental processes become

Fig. 17. Restoration of growth in a girl upon treatment with thyroxine. The two photographs were taken in the same dress at an interval of six months. This child was the first one to be treated with thyroxine. (Courtesy of Dr. E. C. Kendall.)

progressively more sluggish. These symptoms are relieved, often with dramatic promptness, when thyroxine is administered.

Iodine deficiency in childhood may markedly stunt the growth in height. Here also the cure due to thyroxine and the change in general appearance are frequently striking, as in the case of the girl shown in Fig. 17.

Qualitatively, the requirement for iodine might be stated as a sufficient amount of iodine to meet the daily losses from the body and maintain within the body such store as is needed to provide for the manufacture in the thyroid gland and the distribution throughout the body of sufficient amounts of thyroid hormone to support a normal rate of physiological activity, without the gland becoming abnormally enlarged.

Estimates on the total iodine content of the full-grown healthy man vary from about 25 milligrams to about 50 milligrams; or roughly, 1 part of iodine in 2,800,000 or 1,400,000 parts of body substance. The blood and every cell in the body are said to contain iodine, but by far the greatest concentration occurs in the thyroid gland where the normal concentration is about 1 part in 2500 (Curtis and Fertman, 1949, 1951). The body iodine occurs in part as inorganic iodide and in part in organic combination as thyroxine, thyroglobulin, di-iodotyrosine, and possibly other forms. How much iodine must be taken in daily to maintain this store of iodine in the body is not precisely known. According to the National Research Council the requirement is probably about 0.002 milligram to 0.004 milligram daily for each kilogram of body weight, or a total of 0.15 to 0.30 milligram daily for an adult. "This need is met by the regular use of iodized salt; its use is especially important in *adolescence* and *pregnancy*."

If the iodine need of pregnancy is not met by the mother's intake, the tragic condition of myxedema in the baby may result.

When amounts of iodine in excess of the minimal requirement are furnished by the food and drink, an easily mobilized reserve store of iodine is build up in the body. This capacity for storing iodine undoubtedly explains how, in the experiments of Marine and Kimball, the protective effect of a period of intensive iodide dosage extended through five succeeding months when no further supplementary iodide was given.

How May the Needed Iodine Be Supplied?

With the exception of seafoods, which are consistently rich sources of iodine, most foods are too variable in their iodine content to be depended upon to meet the dietary need for this element. It is true that many foods grown in the socalled non-goitrous

regions are rich enough in iodine that their use might supply the whole or a significant part of the nutritive requirement. But in these regions generally the drinking water also shows a relatively high iodine content, often much more than enough to satisfy body demands. Whereas in the goitrous regions, where the drinking water is comparatively poor in iodine and there is consequently greater need to supply this element from other sources, the native plant products may contain only a fraction of the iodine present in the same plants grown in non-goitrous sections!

(It should be emphasized strongly that iodine is an exception—or, at any rate, an extreme case—among the mineral elements with regard to the relatively large variations in the concentration in which it may occur naturally in the same type of plant.)

Thus, while in normal regions the drinking water and natural food products provide the iodine required for the proper functioning of the body, reliance cannot be placed on either of these sources in districts where goiter is known to be prevalent. To prevent this disorder and promote normal nutrition in such regions, it was necessary to find a means of insuring a supplementary intake of iodine by every individual in the community. With this aim, a small amount (one part in 5,000 to 200,000) of sodium or potassium iodide is now being incorporated in the table salt marketed in those sections of the country where goiter was formerly common.

The efficacy of this "iodized salt" as a goiter preventive has now been well established by experience. For the individual in whom the disease already exists, however, the problem of treatment lies in the realm of medicine rather than of nutrition.

EXERCISES

1. Obtain from the United States Public Health Service the most recent available evidence as to the prevalence of goiter in different regions. Is the region in which you live relatively goitrous or relatively free from goiter?

2. Can you explain the prevalence or rarity of goiter in your region by reference to (*a*) relation to the sea, (*b*) relation to the geological formation, (*c*) food habits of the people, (*d*) use of iodized salt?

3. Search the literature for recent evidence on factors other than iodine deficiency which may be involved in the causation of goiter.

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11

ASCORBIC ACID (VITAMIN C)

The Former Prevalence of Scurvy and the Discovery and Identification of the Antiscorbutic Substance

So little did fresh fruits and vegetables figure in the food supply of Northern and Central Europe a few centuries ago, that when Catherine of Aragon came to England it was necessary for the household of Henry VIII to send abroad to get the materials for a salad. And during the period (and in the regions) in which these foods were so scarce for so much of the year, scurvy was so prevalent that medical writers seriously discussed the suggestion that all diseases be regarded as outgrowths of scurvy.

European medical literature, however, has so short a history that we do not know for how long scurvy had been such a scourge: it is known to have afflicted the Crusaders in the thirteenth century, and near the end of the fifteenth century when Vasco da Gama made his historic voyage around the Cape of Good Hope, he reported the death by scurvy of 100 men out of his crew of 160.

The formal medical name for scurvy is *scorbutus;* and things capable of preventing scurvy are often called *antiscorbutics*. Gradually it was learned that this antiscorbutic property is manifested by many "fresh" parts of plants.

In 1535, when Cartier was obliged to winter in Canada on his second voyage to Newfoundland, scurvy killed a quarter of his men. Nearly all the others were severely ill with it, but on advice of the natives a remedy was found in decoctions of the twigs and needles of evergreen trees. Recent investigations of Russian government bureaus interested in the settlement of northern Siberia indicate that leaves and twigs of both pines and spruces may be thus utilized as antiscorbutics. Tolstoy tells in *War and Peace* of the long-standing habit of the Russian peasants to scour the country in

early spring, hunting for and devouring everything green and freshly growing.

Returning to the history of the exploration and settlement of America, we find that, in provisioning for regions which did not afford fresh fruits, thought turned first to wine as a substitute and then to beer as a substitute for wine. And crude, freshly fermenting beer was more or less generally recognized as antiscorbutic. Dr. John Nichols wrote of early New England records which show that shipmasters who brought colonists were careful to make sure that there was someone on board who could look after the malting of barley and the brewing and care of the beer. John Alden, whose name has been immortalized in literary romance, was, Dr. Nichols found, first enlisted primarily as a cooper to have charge of the brewing equipment and the beer barrels. The malting process is, of course, merely a carefully regulated sprouting of the barley grain, which, like other seeds, is not antiscorbutic in the "resting" state but develops the antiscorbutic property as it sprouts. The simultaneous enzyme activity, changing starch to maltose, provides material for the fermentation. Thus a freshly fermenting infusion of (unroasted) malt has the antiscorbutic property of sprouting seeds; but *present-day* beer is so highly clarified that all antiscorbutic value is usually lost.

Lind of the British navy described in his *Treatise on Scurvy* (1757) the treatment of an outbreak of scurvy on shipboard in 1747 under conditions which gave his experience much of the definiteness of a laboratory experiment. He took 12 patients (of the crew of the *Salisbury*) who appeared to be equally scorbutic and treated two by each of six regimes then more or less currently recommended. The two who received the limited amount of oranges and lemons available made dramatic recoveries.

In 1841 the American physician Budd advanced from the concept of an antiscorbutic property possessed by certain foods to the explicit postulate of a definite individual substance (chemical "element" in the terminology of his day), which he predicted would be identified "in a not too distant future." And in 1931–32, King, then of the University of Pittsburgh, first effected the chemical identification of the antiscorbutic substance. His identification was quickly confirmed, and within a short time the substance had been synthesized by more than one method.

During the ninety years between Budd's prediction and its fulfillment by King, much was learned through clinical, field, and laboratory observations.

Government regulations required the carrying of citrus fruit juice by British ships, and its regular issue to all members of the crew on long voyages. This was found to be effective. It also came to be generally recognized that as potato culture had become more common in Europe scurvy had become less common, and correspondingly that the failure of the potato crop in any considerable region meant scurvy in that region the following winter or spring. Thus the failure of the potato crop in Ireland in 1848 was followed both by famine and by a crushing epidemic of scurvy.

In 1906, Hopkins of Cambridge University definitely included scurvy among the diseases due to nutritional deficiency, and in 1907 the Norwegian investigators, Holst and Frölich, published the first of their researches in this field. The clinical work of Hess and the laboratory work of Mendel and his students followed quickly; and these scientific advances enabled army and navy medical men both largely to prevent scurvy and also to systematize the recording and interpretation of the necessarily fragmentary observations made during World War I. Later, when increased numbers of scientific workers were able to return to the fundamental problems of the nutrition laboratories, there was a period in which pioneering laboratory work upon several substances of demonstrated nutritional importance was simultaneously very active before the chemical nature of any of these substances could yet be known.

As a temporary expedient to reduce the confusion in the rapidly growing literature, the term *vitamine* which Funk had coined was combined with McCollum's terms *fat-soluble A* and *water-soluble B* to form the terms *vitamin A* and *vitamin B;* and Drummond, in proposing this system, added antiscorbutic substance as *vitamin C.*

If the alphabetical sequence of the designations had followed the chronological sequence of what we now regard as clearly postulated nutritional concepts, the ABC order of these three substances would be reversed; for the antiscorbutic substance was explicitly postulated as a chemical individual many years earlier than was the antineuritic substance (vitamin B); and the existence of the

latter was apparently known earlier than was that of the fat-soluble substance which came to be called vitamin A.

King and his collaborators worked systematically for years to concentrate and isolate vitamin C as a chemical individual, testing and measuring their progress at each step by quantitative determination of the antiscorbutic potencies of their products. In the early spring of 1932, they had thus completed the physical isolation and chemical identification of the substance investigated as vitamin C. It then became possible to devise methods for its rapid determination, with fair accuracy even in small amounts of material; and thenceforward its investigation has proceeded rapidly.

With vitamin C chemically identified and found to be a relatively simple substance, there yet was difficulty in finding a name of convenient length and satisfactorily indicative of its chemical nature. Hence usage has increasingly adopted the name *ascorbic acid* as being distinctive and as perpetuating the historical association of the substance with scurvy, through the study of which its existence was first postulated and finally proven.

The Nutritional Significance of Vitamin C

In vitro, and presumably in the life processes of plants, the outstanding property of ascorbic acid is that of entering readily into oxidation-reduction reactions. *In human nutrition*, at least equal significance attaches to its function in the formation and maintenance of the intercellular cement substances of the tissues. While most biological teaching tends strongly to emphasize what goes on within the cells, it is just as fundamentally scientific to realize that many of these intracellular activities can proceed normally only on condition that the intercellular cement substance holds the cells in proper relation to each other and to the body fluids which bathe and nourish them.

Wolbach offers, as a result of his pathological research, an impressive array of ways in which body function may be impaired through the effects of shortage of vitamin C upon the integrity of the intercellular material in different bodily organs and tissues:

(1) Hemorrhages, which may occur anywhere in the body, and which are a prominent feature of the classical picture of scurvy. Some-

times the hemorrhages are tiny *petechiae* visible in or through the skin, sometimes crescent-shaped areas at the bases of the teeth, sometimes invisible hemorrhages in the joints, making them stiff and sore. At autopsy, hemorrhages are often found also in the wall of the digestive tract and at the rib junctions.

(2) Structural changes in the gums and teeth, the latter having been considered by some investigators to be the most delicate structurally observable indications of shortage of vitamin C.

(3) Changes in the growing ends of bones, sometimes causing confusion between rickets and scurvy in children.

(4) Defective calcification due to degeneration or lack of proper development of the bone matrix.

(5) Displacement of bones due to weakness of the supporting cartilage.

(6) Anemia due to interference with the functioning of the blood-forming cells in the bone marrow, as well as to the loss of blood by hemorrhage.

(7) Damage to heart muscles, sometimes shown by enlargement of the heart.

(8) Degeneration of muscle structure generally.

(9) Injury to the sex organs.

With shortage of vitamin C constituting the underlying nutritional fault which may show itself in such different ways as these, it is to be expected that constitutional differences among individuals may determine the way in which any one person will suffer from this same suboptimal feature of food supply.

Hence, even though the symptoms may be somewhat confusingly varied, we may still have a clear impression that vitamin C is a nutritional factor of very far-reaching importance.

It must not be thought that nowadays scurvy exists only in remote places or in the minds of alarmists. No less sane a scientist than Professor Hopkins of Cambridge University reported not many years ago an experience which came to his attention in a large school in England. During the winter term at this school the standards of work and play fell to an unsatisfactory level; the boys became listless and irritable, and various minor complaints were reported. Attempts to explain the condition were for some time unsuccessful. At last the suggestion was made that the diet be investigated by some one with modern knowledge of nutrition. The food conditions had traditionally been considered quite satisfactory.

It was found, however, that the diet contained nothing in the way of uncooked foods and practically no green vegetables. A small fruit shop nearby, where the boys had formerly purchased fresh fruit with their pocket money, had been closed for some time. Upon restoring a liberal amount of fresh fruit to the diet the whole trouble disappeared. These school boys had evidently been suffering from incipient scurvy, due to the low intake of vitamin C during the period in which they did not have fruit.

Shortage of vitamin C may begin to be injurious considerably before the classical signs of scurvy appear, and for the reasons indicated above the earliest effects may show considerable individual variation. Hence clear-cut evidence and consensus of opinion as to the incidence of pre-scurvy or early or incipient effects of suboptimal intakes of vitamin C are lacking. There is, however, strong evidence that suboptimal concentrations ("levels") of vitamin C in ostensibly healthy people are more frequent than hitherto realized. Medical surveys of nutritional status, using the delicate methods recently developed, have revealed, in different parts of Canada and the United States, relatively large proportions of people (especially in the low income groups) who are living at relatively low ascorbic acid levels which, even if they do not show gross symptoms of scurvy, undoubtedly mean something less than optimal resistance. For King and his coworkers have shown with guineapigs[1] that relative shortage of vitamin C lowers resistance to bacterial toxins and that this lowering of resistance is demonstrable before ordinary signs of scurvy appear. King has also pointed out that the full benefit of vitamin C to healing wounds requires about ten times as high a daily allowance of this vitamin as is needed to prevent scurvy. Thus if optimal level includes the concept of keeping the body in best condition to meet emergencies, the lowest intakes sometimes accepted as minimal-adequate would need to be multiplied by at least five and perhaps ten to reach the optimum.

Quantitative Metabolism and Requirement in Man

Of the vitamin C which the body receives, a part disappears in the tissues and is evidently consumed in performing its nutritional

[1] Guineapig is preferably written as a single word to mark it as an arbitrary term inasmuch as these animals are not closely related to ordinary pigs.

function; a part leaves the body unchanged, chiefly in the urine; and a part is held by the tissues and fluids of the body.

Extensive studies indicate that normal human blood contains, as an average, between 1.0 and 1.5 milligrams of vitamin C per 100 grams;[2] and the solid tissues (muscle excepted) that are characterized by high metabolic activity normally have higher concentrations of this vitamin.

It is especially noteworthy that the amount of vitamin C contained in the body, the rate at which it is destroyed, and the rate at which it escapes through the kidneys, are all subject to relatively large variation even under such conditions as are frequently encountered in daily life (Fig. 18). We cannot doubt that these differences in "level of vitamin C nutrition" are significant in relation to health and efficiency, and that the problem of human requirement for vitamin C should be considered not simply in terms of prevention of scurvy, but rather as a problem of ensuring the maintenance of such concentrations of vitamin C in the blood and body tissues as are conducive to the highest attainable health under all the vicissitudes likely to be met in the course of our lives. And there are indications that with advancing age the body may need more vitamin C than in the prime of life; or that liberal intake of this vitamin may help to moderate the aging process.

Other things being equal the lower the intake of vitamin C the smaller the amount which appears in the urine; and, simultaneously with low intake and low output, low concentrations of vitamin C in blood have repeatedly been found and are doubtless regularly to be expected (Fig. 18). Such quantitative studies as have been made with spinal fluid indicate that its level of vitamin C content tends to rise and fall with the level in the blood; and it is reasonable to suppose that this is true also of the body tissues generally, though some of them may fluctuate in lesser degree than others.

An intake of 10 to 20 milligrams of ascorbic acid per normal adult per day appears to be sufficient to prevent scurvy or any other grossly manifest symptom of vitamin C deficiency; and may therefore be taken as a standard of *minimal* adequacy.

But many common infections, injuries, and strains or stresses now seem rather clearly to increase the rate of destruction of vitamin C in the body, and thus to raise the nutritional requirement for it.

[2] Sometimes denoted as *milligrams per cent*.

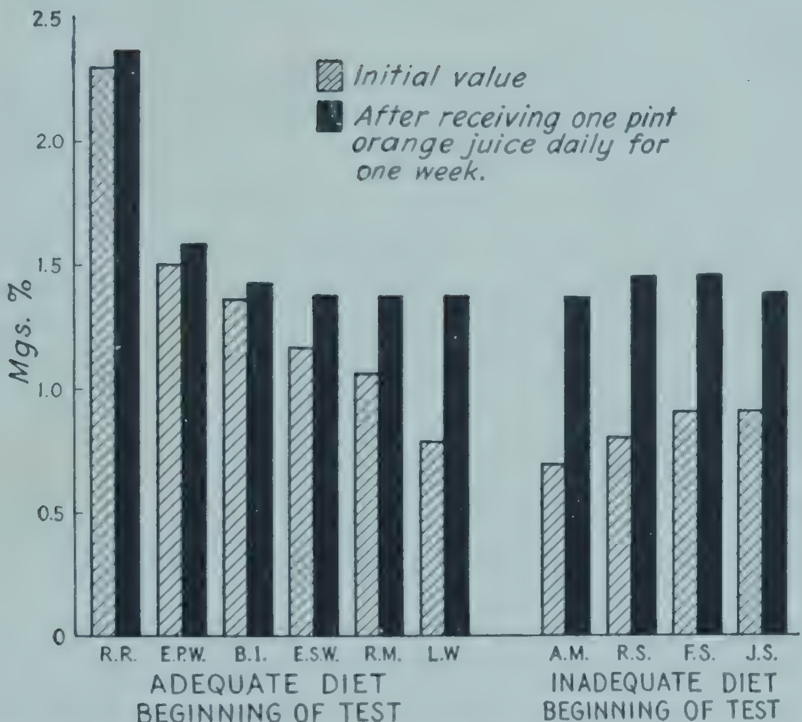

Fig. 18. Vitamin C content of the blood as influenced by diet. The six individuals to the left had all been receiving an apparently adequate diet prior to the beginning of the test. Note, however, the considerable individual differences among them with regard to the initial concentration of vitamin C in the blood (cross-hatched bar), one showing a value distinctly higher, another a value lower than the "usual normal range." The four individuals to the right who were known to have had an inadequate intake of vitamin C prior to the test all showed "subnormal" levels of vitamin C in the blood. After generous amounts of vitamin C in the form of orange juice had been given for a week to both groups, the blood level of vitamin C (solid bar) was found to be about 1.5 mgm. per 100 cc. in all cases except the one individual who showed exceptionally high value throughout. Note that values already normal were slightly increased by the liberal intake. (From Farmer and Abt in *The Vitamins* by permission of the American Medical Association, publishers, and by courtesy of the Milbank Memorial Fund.)

Most students of the subject have therefore come to feel that a *satisfactory standard* must be higher than the minimum arrived at as indicated in the preceding paragraph; and have sought an objective basis for the more liberal standard in the determination of the amount which must be taken into the body in order to keep it in a condition of vitamin C "saturation." Different interpretations have been given to this term, or to the concept it represents, which

is, of course, quite other than that of a saturated solution in the ordinary physical sense.

Generally, the body is spoken of as being "in a condition of vitamin C saturation" when an increase in the level of intake, or a large extra dose, can raise but little if at all the level of vitamin C concentration in the body (usually as represented in the blood), while a large part of the extra intake appears promptly in the urine.

The *Recommended Dietary Allowances* of the Food and Nutrition Board of the National Research Council, aiming at the maintenance of "good nutritional status," provide, *in milligrams of ascorbic acid per day:* for men, 75; for women, 70, rising to 100 in the last third of pregnancy and 150 during lactation; for children under 1 year of age, 30; 1–3 years, 35; 4–6 years, 50; 7–9 years, 60; and 10–20 years, 75–100. For the further details of the recommendations for the last-named period the full table (48) in the Appendix may be consulted.

According to the text accompanying the Recommended Allowances, the suggested intakes at the various ages are 3 to 7 times the minimum level protective against scurvy, but "are not 'saturation' values since more generous intakes result in distinctly higher concentrations in the tissues."

Here, as elsewhere, the artificial concentrates should be considered as drugs to be used only when prescribed by a physician; while the non-medical student of nutrition who desires to increase his intake of some dietary factor should do so by shifting the proportions in which he consumes everyday foods. One who desires 100 milligrams of vitamin C may advantageously take it in the form of seven ounces of average orange juice; or may readily figure an equivalent in the form of some other food or foods from the data of Table 21 below or of Table 47 in the Appendix.

There is no danger that any selection of foods one might make would involve any risk of injury from surplus of this vitamin.

There is, on the other hand, some difference of expert opinion as to how important it is to provide such liberal intakes as to keep the vitamin C level in the body high at all times. From a starting point of excellent nutritional status and all-round health, one may go a long time on a low vitamin C level before visible signs of scurvy appear. The British Medical Research Council recently reported a study on 10 conscientious objectors who were maintained

on a diet supplying less than 1 milligram of vitamin C daily. Though the blood plasma level of vitamin C dropped progressively until it was practically zero, it was as much as 100 days longer before clinical scurvy developed. The first signs to appear were enlargement and keratosis of hair follicles, about 17 weeks after the start of the vitamin C deficient diet. The typical gum changes of scurvy appeared only after about 26 weeks of (practically) total deprivation of dietary vitamin C. Delayed healing of experimentally produced wounds was also observed, but not as an early effect of the deficiency. Scurvy was cured by 10 milligrams of vitamin C daily; and another group of volunteers were protected against scurvy for up to 424 days on an intake of 10 milligrams of vitamin C. Still another group which received 70 milligrams of vitamin C daily seemed to have a slight advantage over those with 10 milligrams in certain tests of physical fatigue, but the overall conclusion of the committee in charge of the experiment was that: "As long as there is no evidence to support the view that an intake of more than 30 milligrams daily has beneficial effects, there is no basis for recommending an intake greater than that amount."

The question of vitamin C intake is a point of major divergence between the Recommended Dietary Allowances of the National Research Council in this country, and the current recommendations of Canada and Great Britain.

Many people no doubt go through life "passably healthy" and doing ordinary work with bodily levels of vitamin C chronically much below physiological saturation. Thus the Milbank Memorial Fund studies of nutritional condition in New York City high school students showed plasma ascorbic acid levels below 0.6 milligram per 100 grams in 48 per cent of 1059 boys and in 46 per cent of 1088 girls. These low levels were considered "indicative of insufficient intake" by these research workers, and when the research was extended to include quantitative inquiry into the kinds and amounts of foods consumed, it was concluded that vitamin C came next after vitamin A and calcium in the frequency with which the dietary fell below the current standards.

Since studies of nutritional status of populations in many sections of the United States and Canada have revealed a rather high incidence of shortages of this vitamin, and since the data of food consumption studies of Stiebeling and coworkers also warn us that

many families still live on dietaries of undesirably low vitamin C value, there is a general trend toward acceptance of the relatively liberal Recommended Allowances and correspondingly a growing emphasis upon the vitamin C values of foods.

Conservation of Vitamin C in the Preparation and Preservation of Foods

From the earliest scientific conception of scurvy as due to the lack of an antiscorbutic substance, it was recognized that in general fresh foods have more and preserved foods have less of this factor. As the concept became clearer, the statement came to take the form that not only are some foods, such as citrus fruits, relatively rich in this factor while others such as bread, butter, meat, and sugar are poor or lacking in it; but also that it is an unstable factor so that cooking and preservation are apt to diminish whatever antiscorbutic value the food originally possesses.

Now that all of the more familiar vitamins are known as distinct chemical individuals *not* closely related in their chemical and physical properties, we see that it is unscientific to try to make broad and simple generalizations or comparisons, for the behaviors of the vitamins will arrange them in different sequences according to the particular chemical or physical condition whose influence is being considered. Yet for most practical purposes we may still regard vitamin C as the most easily destroyed of the known vitamins.

Because many familiar fruits and vegetables, such as apples, cabbage, and peas, may lose a considerable proportion of their vitamin C value in ordinary cooking, it has become customary to emphasize raw food in this connection, and to regard this vitamin as thermolabile liable to be destroyed upon heating. Strictly speaking, it is not so much destroyed by heat itself as by a process of oxidation which is accelerated by increase of temperature. The rate of destruction is lower when air is excluded by steam or by vacuum; and it is higher when acidity has been reduced or alkalinity increased by the addition of soda to the food. The destruction of vitamin C is also catalyzed by the presence of even very small amounts of copper. In addition to all these environmental influences (and perhaps others, as yet less clearly defined) there are properties within the natural foods themselves which affect the conserva-

tion or deterioration of their vitamin C values. Some contain enzymes which catalyze the destruction of vitamin C. In general the more acid foods hold their vitamin C better; but if cabbage juice is brought to the same acidity as tomato juice it still will lose more of its vitamin C on heating, because of the natural, inherently higher, oxidation potential of the juice of the cabbage.

The destruction of vitamin C upon heating in solution, as in the juices of typical foods, is a process which proceeds at a rate which can be measured experimentally and which has been studied quantitatively with reference to the influence of temperature, time

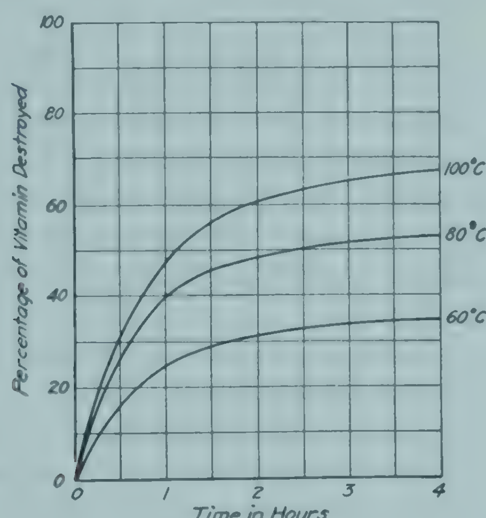

Fig. 19. Curves representing the rates of destruction, at different temperatures, of the vitamin C of tomato juice at its natural acidity.

of heating, the acidity or alkalinity of the solution, and other factors.

In the case of tomato juice of natural acidity it was found that boiling for one hour destroyed practically 50 per cent, and boiling for 4 hours destroyed practically 68 per cent of the antiscorbutic vitamin. At lower temperatures there was less destruction in any given interval of time. Figure 19 shows the time curves of the heat destruction of the vitamin at 60°, 80°, and 100°C. It will be noted that, throughout the entire range of times and temperatures covered by these experiments, the destruction was always greater the higher the temperature whatever the time of heating selected for the comparison; and also that at whatever temperature the material was heated the destruction of the vitamin also continued to become greater the longer the heating was continued.

Thus both time and temperature are important factors in the heat destruction of vitamin C and neither the time nor the temperature can be treated with indifference in any heating operation in which it is desired to conserve as much as possible of the antiscorbutic property of the food. Both time and temperature of heating must be held to the lowest practicable minimum if vitamin C is to be conserved to the best advantage.

The best conservation of the antiscorbutic value of the food also demands that one avoid adding any soda or other alkali to the food, or to the water used in its cooking.[3]

Not only is vitamin C more readily destroyed in an alkaline than in an acid solution; any decrease of acidity, even though the material may still remain acid, means that a greater percentage of the vitamin will be destroyed under the same conditions of time and temperature. Thus tomato juice, which lost 50 per cent of its vitamin C in one hour at 100° C. at natural acidity, lost 58 per cent under the same heat treatment when it had been about half neutralized, and 61 to 65 per cent when it had been made very faintly alkaline.

Alkalinity, even in slight degree, appears to be distinctly deleterious to vitamin C even at ice-box temperature, for when the solution last mentioned was stored in an icebox for from one to five days it was found to have lost much the largest part of the vitamin C which had survived the hour of heating. In this case, however, the material was not protected from contact with air during storage.

It is quite clear that one should not speak of the vitamin as being "destroyed at" a certain temperature; but rather as being *more rapidly* destroyed the higher the temperature. The question is not so much *whether*, but rather *in what degree* (or at what rate), the vitamin is destroyed "at boiling," "at steam-table temperature," etc.

[3] In certain laboratory tests (Johnston, *et al.*, 1943), addition of sodium bicarbonate hastened the rate at which peas became tender, and if cooking was stopped *immediately* upon reaching this point, the shorter time of cooking just about balanced the added alkali effect, so far as loss of vitamin C was concerned in the case of this food. Since, however, it is not to be expected that the housewife will be able to determine precisely the quantity of sodium bicarbonate to give this effect or always to stop cooking and serve the peas at exactly the moment "doneness" is reached, addition of soda appears to be undesirable as a household practice.

If, for instance, the material shown in Fig. 19, after losing 20 per cent of its vitamin C at 100°C. (boiling temperature) was thereafter kept hot for serving by placing it on a steam-table at 60°C. the destruction would continue at, of course, a lower rate.

The Council on Foods of the American Medical Association (in the July 15, 1939 *Journal* of that association) issued a report on "Allowable claims for the vitamin and mineral content of canned fruits and vegetables intended for infant feeding" which includes a Decision that sufficient experimental evidence has accumulated to warrant the view that vitamin A and riboflavin are little affected by good modern canning procedures, but that thiamine and vitamin C are more or less adversely affected, "the degree of destruction depending on the characteristics of the food itself, the time and temperature of processing, and possibly other factors." They proposed thereafter to recognize claims for thiamine and vitamin C values of such canned foods only when "supported by acceptable evidence of the potency of the finished product."

One should, therefore, not attempt to answer broad, undiscriminating questions as to whether or to what extent a given vitamin is destroyed by a given cooking or canning process; for the rate of such destruction differs too widely among different foods, and is also influenced by too many environmental conditions.

It may safely be said, however, that among the conditions which are favorable to conservation of vitamin C are: to minimize time of exposure, temperature, and contact with air or dissolved oxygen, and to add no soda. Whipping air into the food while hot, as in preparing mashed potatoes, favors destruction of vitamin C which may have survived the actual cooking process; and, if the mashed potatoes are kept warm, as on a steam-table, for some time before serving, the loss continues.

As vitamin C is readily soluble in water, the rejection of cooking water, or of the fluid contents of the can, may involve a loss no less serious than that of the actual destruction which takes place in the cooking and canning processes. In some careful experiments the loss in cooking has been found to have been even much more largely due to the dissolving away of the vitamin than to its actual destruction. Thus, Wellington and Tressler (1938) found that in the boiling of shredded cabbage less than one-sixth of the original vitamin C was destroyed, while about two-thirds of it was lost from

the vegetable in the sense that it passed into the cooking water. When larger pieces of cabbage were boiled, the amount extracted was less. The utilization of "pot liquors" in making soups and stews has doubtless helped to protect many poor families from scurvy.

An important further consideration in conserving the vitamin C value during cooking is to bring the food as quickly as possible to the boiling temperature, in order that the vitamin C-destroying enzymes naturally present in many foods may be inactivated by heat. When foods are warmed only slowly, these enzymes have an opportunity to act for a much longer time. The procedure of blanching (short exposure to high temperatures in boiling water or steam) of foods before freezing, also serves to inactivate the enzymes and reduce the deterioration in vitamin value in subsequent storage. Blanching inevitably occasions some loss of vitamin C due to solution, but properly blanched vegetables hold their remaining vitamin value well in frozen storage at 0°F. or below; and, if handled and cooked carefully may reach the table with vitamin C values close to those of the same food cooked when fresh. Blanching is also applied in the commercial canning of vegetables. The canning industry has been alert to ways of improving the nutritive quality of the final product (see *Review*, 1949) including study of losses which occur during storage of the canned product. It is evident that, even for canned foods, cool storage is helpful in conserving vitamin C value; and that holding over commercially or home-canned foods a second season is generally a poor practice from the viewpoint of the vitamin value of the final product.

In Table 21 are included a number of values for the vitamin C in cooked and canned, as well as in raw, foods. These values for cooked foods were taken from the *Agriculture Handbook No. 8*, and "are based on studies in which fair-to-good cooking procedures were followed." The literature includes many instances in which the losses were significantly greater or less than shown here. Hence the caution to treat the values in Table 21 as approximations only, and to recognize that in many instances the homemaker may, by taking advantage of scientific knowledge, bring a greater proportion of the vitamin C to the table. On the other hand, it should be stressed again that cooked foods that have been held for a considerable time on a steam-table before serving may be very much lower in vitamin C value than the figures in Table 21 would sug-

gest. Persons who habitually take their meals in restaurants will do well to insure an adequate intake of vitamin C from sources other than cooked foods.

Cabbage intended for slaw, or greens for salad, will hold the vitamin C better if kept cool and crisp till serving time; for vitamin C is lost in wilting, and disappears, as a result of enzyme action, much more rapidly when the plant tissue has been broken down by chopping or crushing than in the intact leaf.

TABLE 21. *Vitamin C in the Edible Portion of Typical Foods, Raw and Cooked or Canned: Milligrams per 100 Grams*

Food	*Raw*	*Cooked*	*Food*	*Raw*	*Cooked*
Apple	5	2	Grapefruit	40	35[a]
Asparagus	33	23	Kale	115	51
		18[a]	Lettuce, head	8	
Bananas	10		loose-leaf	18	
Beans, Lima	32	15	Liver	31	31
		8[a]	Milk, pasteurized	1	
snap or string	19	14[b]	Mustard greens	102	45
		10[c]	Orange or juice	49	42[a]
Beet greens	34	15	Peas, green	26	15
Broccoli	118	74			9[a]
Brussels sprouts	94	47	Peppers, green	120	
Cabbage	50	31[b]	Pineapple	24	9[a]
		19[c]	Potatoes	17	17[d]
Cantaloupe	33				7[e]
Cauliflower	69	28	Strawberries	60	
Chard	38	17	Sweetpotatoes	22	23[d]
Cherries	8	6[a]	Tomatoes	23	16[a]
Corn, sweet	12	8	Turnip greens	136	60[b]
		5[a]			45[c]
Cress, water	77				

[a] Canned.
[b] Cooked in a small amount of water for only a short time.
[c] Cooked in large amount of water for a long time.
[d] Baked.
[e] Mashed.

Even in intact raw fruits and vegetables, a gradual loss of vitamin C occurs on storage, though, as King (1951) summarizes it, "Acidic foods (oranges, lemons, grapefruit and tomatoes) and some foodstuffs that retain a 'living condition' during storage (potatoes, pep-

pers, cabbage, turnips, avocados and bananas) generally retain their vitamin C content fairly well." Even so, potatoes, which may customarily be stored some months, thereby lose an important fraction of their vitamin C. According to *Agriculture Handbook No. 8*, freshly dug potatoes which contain about 24 milligrams of ascorbic acid per hundred grams may lose about half of this in three months, and as much as two-thirds in six months, of storage.

Quantitative Distribution of Vitamin C in Foods

There is much of both scientific interest and practical value in a consideration of the different types of foods as sources of vitamin C now that we are beginning to appreciate the great importance of this constituent of our food to our nutritional wellbeing and resultant health and efficiency.

In the food supply of the nation, citrus fruits and tomatoes supply one-third of the total vitamin C. Next comes the group of "leafy, green, and yellow vegetables" which provides about one-fourth of the ascorbic acid as it comes to market but, owing to losses in cooking, probably a somewhat smaller proportion of the amount actually consumed. Potatoes and sweetpotatoes contribute about one-sixth of the total; and a like proportion is provided by other vegetables and fruits; while milk and its products make up most of the remaining supply.

Thus we derive probably nine-tenths of our vitamin C from fruits and vegetables, and most of the remainder from milk. Doubtless the flesh foods could be made to furnish a larger proportion if we ate them, as the Eskimos do, in larger amounts, with less intervention of storage and cooking between slaughter and consumption, and with a reversal of our usual practice of taking the muscle meats for ourselves and giving the glandular organs to the dogs. Another and perhaps more important consideration in clearing up what some regard as an inconsistency between our view of vitamin C and some of the reports upon food habits of carnivorous peoples is that the latter have sources of vitamin C which are apt to escape the attention of explorers and even anthropologists. The natives of Kamchatka were anthropologically described as living exclusively on meats and fish; but a later more meticulous investigation revealed the fact that they also eat berries, bark, and leaves. Evi-

dently so did those Canadian Indians who were supposed to be carnivorous until occasion arose for them to teach Cartier's men the importance of evergreen twigs and leaves as antiscorbutic food.

There are probably no strictly carnivorous peoples; for it is much more probable that explorers who think they have found such have failed to observe or to appreciate the significance of the eating of berries and the chewing of bark, roots, and twigs. Of course it may also be true that people descended from untold generations of Arctic ancestors may have intensified, as a characteristic of survival value under their conditions, the property of being able to get along with less vitamin C than we require.

To return to the consideration of the different types of foods as sources of the vitamin C of our normal dietaries, it is noteworthy that the breadstuffs and cereals which furnish such a large proportion of our food calories and protein are such insignificant sources of vitamin C in the forms in which we ordinarily eat them. These seeds, however, and also the mature legumes, form vitamin C when they germinate, so that, in lack of other adequate sources, cereal or legume seeds may be germinated and eaten with their young sprouts. Evidently there is here some process of change which the sprouting seed performs efficiently; and which our bodies perform very inefficiently if at all. In the plant cycle too, it would seem to be in some sense a reversible process; the young pea or the green Lima bean is a good antiscorbutic, loses this property as it matures, but regenerates it when sprouting. The oxidation-reduction or "respiratory" behavior of vitamin C *in vitro* here finds a clearcut relation to metabolism in the plant, while in animal metabolism its behavior in this direction is as yet somewhat overshadowed by the importance of its function in the making and maintenance of intercellular substance, as mentioned earlier in this chapter.

Among edible seed pods, *green peppers* have been found to be excellent, and *string beans* good sources.

Dark green leaves, such as *kale, watercress, mustard greens*, and *turnip greens*, are excellent, and *cabbage* is a good source of vitamin C. It is noteworthy that these greens, while showing large cooking losses, are yet excellent sources of vitamin C after cooking because their initial content of this vitamin is so high. *Lettuce* is less rich than the other leaves mentioned, and there is an important difference between headed and loose-leaf lettuce in this respect.

The flowerbuds, *broccoli* and *cauliflower*, are excellent, and *asparagus*, a succulent growing tip, is a good source.

Among roots and tubers, potatoes, sweetpotatoes, rutabagas, and turnips may be mentioned here. *Potatoes* and *sweetpotatoes*, while containing vitamin C in distinctly lower concentration than do some other common foods, are yet of great importance as antiscorbutics because of the quantities in which they are consumed; and, at least when baked with the skins on, they need lose little if any vitamin C.

Turnips and *rutabagas* have high vitamin C value when eaten raw. They and their juices have served as important antiscorbutics in wartime.

Among fruits, the citrus—especially oranges and grapefruit—and tomatoes, which are botanically fruit though classified commercially as a vegetable, are the sources of outstanding importance and qualified for increasing prominence in the dietary on the grounds of economy and general acceptability. Milne, in his essay on fruit, gave first place to the orange, and returned to it for his peroration! Beside its many other virtues, the *orange* is one of the most potent and popular of antiscorbutics. The *grapefruit* is about four-fifths as rich in vitamin C as the orange, and has a fine flavor all its own. Delicious also is a mixture of grapefruit and orange juices. The *frozen concentrated citrus juices* which have achieved such prominence in recent years retain a high proportion of the vitamin C as well as the flavor of the fresh fruit.

Tomatoes are considerably less rich than grapefruit and oranges in their average vitamin C contents. Like them, however, tomatoes hold their vitamin value well when preserved by cold storage or canning, and the canned product is economical and available almost everywhere at all seasons of the year. Often in recent years, citrus fruits have been about as cheap as canned tomatoes, but at times when oranges have been expensive the juice of canned tomatoes has been largely substituted for orange juice in infant feeding.

Apples are more variable and less potent than citrus fruits as antiscorbutics. Having been so widely cultivated, apples have become differentiated into well marked varieties, some of which differ from each other as much, in their vitamin C content, as if they were different species. Several years ago Zilva discovered Bramley's Seedling to have outstanding vitamin C value among English

apples; and more recently Maynard has recognized a New Zealand variety as a still richer source of this vitamin. Yet to recognize each variety separately in ordinary nutrition work would be prohibitively cumbersome. For present purposes therefore we present in Table 21 an average of the middle group of varieties.

Among the small fruits, *black currants* have played an important part as antiscorbutics in Great Britain during World War II. *Rose hips* are also reported very high in vitamin C, and were used during wartime. *Strawberries*, fresh or frozen, are a good source of vitamin C, and doubtless other berries both cultivated and wild have served human nutrition in this respect more significantly than has been appreciated.

EXERCISES

1. Purchase oranges, grapefruit (or canned grapefruit juice), apples (noting the variety if known), and bananas in your local market, recording the cost of each purchase and determining the weight of its edible portion. How do these fruits compare in pecuniary economy as sources of vitamin C?

2. Compare apples, bananas, oranges, and grapefruit (or its juice) as to the amount of vitamin C furnished (*a*) in each 100-Calorie portion; (*b*) per gram (or per 100 grams) of protein. Arrange these fruits (and perhaps others) in the order of their merit as a means of increasing the vitamin C value of a dietary with the least change in its total calories, or total protein, or both.

3. Prepare a critical compilation and discussion of all information afforded by the library facilities available to you, on the extent of the losses of vitamin C involved in different recognized methods of cooking and serving potatoes. Taking account of all losses, what percentage of the vitamin C content of a raw potato probably actually enters the nutrition of the consumer? Could this be materially improved without undue change of household customs? If so, how?

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12

THIAMINE (VITAMIN B_1)

Discovery and Identification of the Substance Temporarily Called Vitamin B and Now Named Thiamine

The existence of the substance now named *thiamine* was discovered both through studies of the disease beriberi and through experiments in normal nutrition. Here, as often, discovery was a process of gradual accumulation of evidence until finally it became convincing.

Beriberi manifests itself primarily as a nerve disease and usually appears first as a weakness and loss of neuromuscular coordination in the feet and legs, equally on both sides of the body. In formal terminology it is a *multiple peripheral neuritis*. It has been most prevalent in the Orient.

In 1878–1883, when the entire enlisted force of the Japanese navy was about 5000 men, each year's sick lists showed from 1000 to 2000 cases of beriberi among them. Takaki, as a patriotic son of Japan and medical officer in her navy, could not reconcile himself to this enormous annual morbidity of 20 to 40 per cent from this one disease. Careful study convinced him that it was not due to tropical climate, for British crews in tropical waters were not thus affected; nor to lack of care in sanitation, in which he found the Japanese as scrupulous as other sailors. He obtained authority for a large-scale experiment with the ration. Two ships each carrying about 300 men were sent in succession over the same long cruise but with different rations. On the first ship, which was furnished with the then standard Japanese ration containing a greatly predominant amount of white rice, more than two-thirds of the men suffered from beriberi; while on the second ship, with a ration in which part of the white rice was replaced by barley, vegetables, fish, meat, and canned milk, only a few men developed beriberi, and these

were found not to have eaten their share of the new foods. So convincing was the evidence, and so striking the contrast, that within a very short time thereafter Takaki was able to obtain a similar change of ration throughout the Japanese navy and this change was followed by a prompt decrease in beriberi cases, from a very high percentage to a mere fraction of one per cent.

The reported figures were as shown in Table 22.

TABLE 22. *Beriberi in the Japanese Navy (1880–1889)*

Year	*Total Force*	*Cases of Beriberi*	*Percentage*
1880 Old ration	4,956	1,725	34.81
1881 " "	4,641	1,165	25.06
1882 " "	4,769	1,929	40.45
1883 " "	5,346	1,236	23.12
1884 Ration changed	5,638	718	12.74
1885 New ration	6,918	41	0.59
1886 " "	8,475	3	0.04
1887 " "	9,106	0	0.00
1888 " "	9,184	0	0.00
1889 " "	8,954	3	0.03

Takaki received prompt and generous official recognition for this really great achievement in practically ridding his country's navy of this disease which had previously been so prevalent; he was promoted, made a baron, and appointed the permanent head of a government hospital and training school in Tokyo. Yet there was a long lag not only in popular but even in scientific and professional understanding of what he had accomplished.

Why was it so many years before the people of the Orient generally began to share the benefit from what had been demonstrated so clearly and acted upon so promptly in the Japanese navy? Takaki had really rid the navy of beriberi by changing the ration, and he had been explicit in saying so. He had even emphasized the fact that the fault in the older ration was nutritional. He had stated the facts as he saw them clearly and emphatically enough; but with world medical opinion, and so with the people generally, his statements remained ineffective because his explanation was inadequate. He attributed the superiority of the reformed ration

simply to its higher protein content, which others rightly regarded as unconvincing. It was a time of great activity in the sanitary applications of the then new and brilliantly developing science of bacteriology; and natually some advances in sanitation had been made in the same period in which Takaki had secured the reform of the ration. So with no adequate nutritional explanation at hand, it seemed to most medical men more probable that the diminished frequency of the disease in the Japanese navy was due to some sanitary cause, even though no infective agent had been discovered. Hence Takaki's work was largely forgotten, and most of those who had to deal with beriberi regarded it as probably due to some undiscovered infective agent.

Such was the view of the American army medical officers when they took over the Philippines during and after the war with Spain. Their striking experience with beriberi in the Bilibid prison at Manila was, however, very influential in reviving the nutritional view of the disease.

When officers of the United States army took charge of this prison, they found what at first appeared to them as an abuse in that the poor prisoners accustomed to live so largely upon rice had been fed with rice of low commercial quality, uneven in size and dark in color. This they promptly replaced by "high grade" rice, consisting of uniform, plump, well polished, white kernels. Notwithstanding their attempts at better and more humane treatment of their prisoners, however, these officers were soon distressed by an epidemic of beriberi in their prison population.

The monthly record ran as shown in Table 23 on page 220.

During the first several months of the epidemic every effort at further sanitary improvement was made, the responsible medical officers thinking at first only in terms of the theory that beriberi was due to infection. Failure of their earnest efforts led them to further study of the literature of beriberi, and in the light of the papers which Takaki had published several years before and which had been generally forgotten meanwhile, they finally began to think that the nutrition hypothesis might be worthy of trial. Accordingly, a change of ration was then made; and it was followed by practical disappearance of the disease in the course of about three months (Table 23).

It was at about the same time with this experience in the Bili-

TABLE 23. *Beriberi in the Bilibid Prison (1901–1903)*

Year	*Month*	*Cases*	*Deaths*
1901	November	2	0
Ration changed (see text)			
1901	December	52	2
1902	January	169	12
1902	February	1087	16
1902	March	576	15
1902	April	327	15
1902	May	310	19
1902	June	451	17
1902	July	233	33
1902	August	571	24
1902	September	522	31
Ration changed again October 20th			
1902	October	579	34
1902	November	476	8
1902	December	89	3
1903	January 1–15	4	0

bid prison that a nutritional interpretation was given to the observations first published by Eijkman, a Dutch physician working in the East Indies, upon "an illness of fowls similar to beriberi." He noticed that such a disease developed in fowls which lived in the bare yard of a prison hospital and subsisted almost entirely upon leftover rice from the prisoners' tables. In systematic trials he found that by confining fowls strictly to a polished-rice diet he could induce experimental beriberi with great regularity. Eijkman, however, did not at first explain the experimental disease in direct nutritional terms but rather upon the hypothesis of the presence of some unknown injurious substance; so that, as English writers afterward expressed it, "the pharmacological bias" at first prevented the nutritional significance from being seen. It was in papers published after the turn of the century and dealing with the work of Grijns as well as of Eijkman, that the experimentally induced disease was first clearly stated to be a *nutritional* polyneuritis.

Then followed about a quarter-century of very active search for the *antineuritic substance*. Several groups of investigators in different countries contributed toward the working out of methods for

the separation of this substance and the study of its chemical nature; which was ultimately completed by R. R. Williams and his associates who also discovered a method of synthesizing this material on an industrial scale. Williams proposed *thiamine* as a short name suggestive of the chemical nature of this substance.

Even today, half a century after the clear demonstration of the nutritional nature of beriberi, and two decades after the anti-beriberi factor became available in quantity, beriberi continues to be prevalent among practically all the rice-eating populations. Williams (1953) estimates that "it is probable that 10 per cent of the population of rice-eating Asia could be shown to exhibit mild symptoms of the disease." Severe deficiency, leading to death, is also common. In the Philippines, for instance, "it has long rated as second only to tuberculosis as a cause of death." The reason lies chiefly in the dependence of these populations on rice as the main item in their diet, and the preference for the highly milled white rice. In Bataan (Philippines) a large-scale trial of rice fortified or enriched with thiamine has strikingly reduced the mortality from beriberi (from 263 to 28 per 100,000), and the incidence also by about 89 per cent (see Salcedo, *et al.*, 1950; Burch, *et al.*, 1952). One of the most pressing nutritional problems on a worldwide scale is the reduction of the incidence of beriberi.

In much of the earlier experimentation, yeast was used as the source of "water-soluble B vitamin." Long before thiamine had been separated in pure form it became evident that the "vitaminic" value of yeast involved many more than this one substance; and for these collectively the terms "vitamin B complex" and "B group of vitamins" came into use, with subscript numerals often applied to identify individual members of the group. As the chemical nature of these individual substances has become clear, more distinctive names have been coined (e.g., riboflavin for vitamin B_2, pyridoxine for vitamin B_6, cobalamin for vitamin B_{12}), but the old B-vitamin terminology is still widely used.

Nutritional Functions of Thiamine

Almost as soon as its antineuritic properties were discovered, vitamin B_1 was shown to be essential to growth and to the maintenance of a good appetite.

An illustration of its relation to growth may be seen in Fig. 20. Seven rats of a litter were fed, one at a thiamine level but little above that required to prevent deficiency disease, and two each at three successively higher levels. Although all were healthy, the rate of growth was quite definitely determined by the thiamine intake, other conditions being uniform.

The effects upon growth and upon appetite may well be interrelated; and to the favorite conundrum of Osborne and Mendel, "Does he eat more because he grows faster, or grow faster because he eats more?" the best answer is probably, "Both."

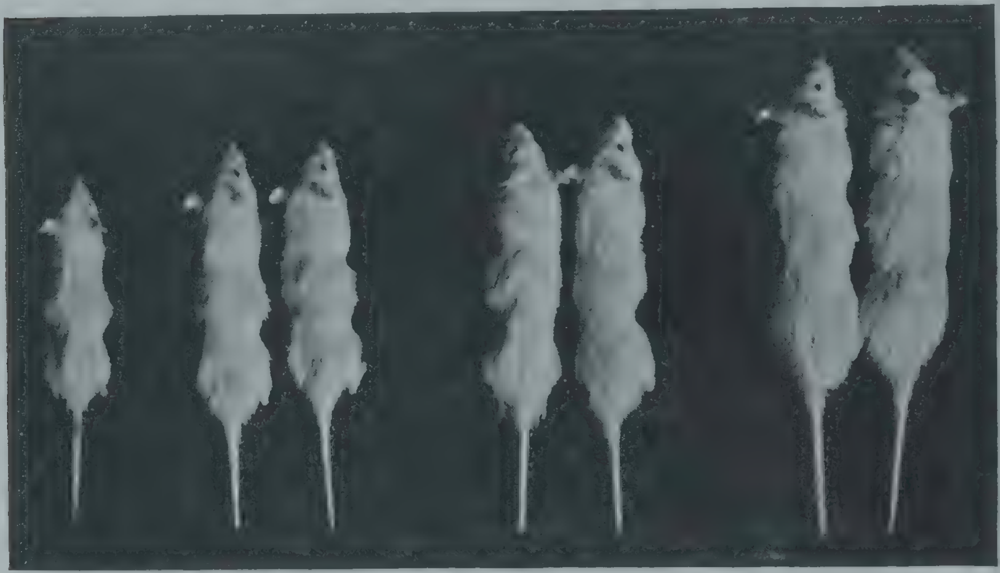

Fig. 20. Growth of healthy individuals as influenced by the level of thiamine, the food being allowed *ad libitum*. (See text.)

The relation to appetite is, however, specific in two senses: (1) while appetite may decline as the result of any of several vitamin deficiencies, no other known vitamin has such a prompt and apparently direct effect upon appetite as has thiamine. (2) The relation to appetite is also specific in the sense that it is a true effect upon appetite as a physiological condition and function of the body, and not merely a matter of making the food appetizing. For even when the vitamin is given separately the experimental animal will return with appetite, and often with dramatic promptness, to the same food which it has previously refused. A similar relation between thiamine intake and appetite has frequently been observed

in man. In some instances, it has been suggested that thiamine promotes appetite even in individuals who are not thiamine-deficient; but not all investigators hold this view.

Thiamine, combined with phosphate to form *cocarboxylase*, plays an essential role in the metabolism of carbohydrates in the body cells. Many years ago, Peters and his coworkers at Oxford found an abnormal accumulation of lactic acid and pyruvic acid in the brain of pigeons which had been kept on thiamine-deficient food; and showed that sections of such brain tissue did not have the same power as did parallel sections from a normal brain, to oxidize glucose in a suitable respiration apparatus. When thiamine was injected into the deficient pigeons, the brain tissue was restored to its normal power of burning glucose completely to carbon dioxide, and the accumulation of the intermediate products, lactic and pyruvic acids, ceased.

Williams and Spies emphasize the view that similar or analogous relationships exist in all the various tissues in which carbohydrate metabolism occurs; thus explaining the helpfulness of liberal thiamine intake in widely varied physiological and clinical conditions.

Thiamine has been shown to affect heart function in experimental animals, one effect of a deficiency being a slowing of the heart rate (*bradycardia*), another the development of lesions of the myocardium (heart muscle). Heart failure ("beriberi heart") may occur also in acute thiamine deficiency; and some cases of heart trouble in this country have been attributed to thiamine deficiency, though there is wide divergence of current opinion as to how frequently this is the real explanation (see Blankenhorn, *et al.*, 1946; Wohl, *et al.*, 1954).

Human Requirements

Since thiamine is essentially concerned in the oxidation of carbohydrates, the principal source of food energy, it is logical to consider the thiamine requirement in terms of the total energy requirement. In experimental animals it has been found that the need for thiamine is less on diets which are high in fat than on isocaloric diets which are high in carbohydrates. This socalled "thiamine-sparing" effect of fat is attributed to the fact that fat metabolism does not require cocarboxylase. It might therefore be more precise to consider the thiamine requirement with reference

to the carbohydrate intake. However, this appears to be unnecessary, since, according to Elvehjem (1951), "the human diet may rarely undergo sufficient change in fat content to alter materially the thiamine requirement." Conditions, such as fever and hyperthyroidism, which increase the total metabolism, do apparently increase significantly the thiamine requirement; as do pregnancy, surgical shock, and probably other stresses.

Williams and Spies (1938) included in their monograph very careful estimates of the amount of thiamine required to prevent beriberi; but more recently they, in common with nearly all students of the subject, have come to take a view which leads to a distinctly higher estimate of normal nutritional requirement than merely that amount which prevents beriberi. This newer view owed its origin largely to investigations made in Wilder's laboratory, in which volunteers have remained for relatively long periods on low-thiamine diets under the constant observation of physicians who gave special attention to the detection of evidences of slight deficiency through signs which under ordinary conditions might easily go unrecognized. Wilder writes of these symptoms as impairments of emotional stability and of mental and physical efficiency which precede the more noticeable signs of thiamine deficiency by weeks or months. The subjects were said to become depressed, irritable, quarrelsome, uncooperative, and fearful. After six months of such moderate restriction and having shown the milder symptoms for months with entire clearness to the physicians especially practiced in detecting them, there still was no sign of the characteristic symptoms of beriberi, such as polyneuritis and heart failure. Hence it is our present view that human requirement is to be judged not simply as the small amount which suffices to prevent beriberi, but as the larger amount required to prevent the much earlier signs of a relatively mild neurasthenia.

Because of the subjective nature of some of the criteria applied by the Wilder group, other investigators have sought a more objective measure of the borderline states of thiamine nutrition. Some have measured the thiamine level in the blood; others the urinary thiamine excretion and the thiamine clearance before and after saturation (in tests similar to those used for vitamin C); still others, the pyruvic acid of the blood; while Horwitt and his associates have devised an index based on the lactic and pyruvic

acid levels of the blood after glucose administration followed by standardized mild exercise, which they believe gives a truer clue to borderline degrees of thiamine deficiency than any of the simpler measures.

Bringing together the evidence of various sorts, the Food and Nutrition Board of the National Research Council considers that "the *minimal requirement* of adults may be considered to be approximately *0.23 milligrams [of thiamine] for each 1000 Calories.*" Measurements of urinary excretion of thiamine in infants (Holt, *et al.*, 1949), as well as consideration of the amounts of thiamine in breast milk and cows' milk formulas, were found to suggest that "the minimum requirement of the infant in relation to calories is similar to that of the adult" and "it is assumed that the same values would prevail through the various ages of childhood and adolescence."

In view of (1) the large individual variations with respect to thiamine need, (2) the inability of the body to store large quantities of this vitamin, and (3) the many stresses known to deplete the body stores and/or augment the requirement, the *Recommended Daily Allowances* were set at a little more than twice the estimate of average minimum requirement—*about 0.5 milligram of thiamine per 1000 Calories* for nearly all the age and activity groups. For fairly active men, the allowances thus vary with age from 1.3 to 1.6 milligrams, and for women from 1.0 to 1.2 milligrams, increasing to 1.5 milligrams during the last third of pregnancy and during lactation. For infants under a year the allowances range from 0.3 to 0.5 milligram; for children 1–3 years old, 0.6 milligram, 4–6 years old, 0.8 milligram, 7–9 years old, 1.0 milligram; for girls 10–20 years old, 1.2 to 1.3 milligrams, and for boys 10–20 years old, 1.3 to 1.9 milligrams per day, varying directly with the energy allowance.

For *adults* with unusually large energy needs, it is not considered necessary to increase the thiamine allowance in the same proportion as the calories but an additional 0.2 milligram of thiamine is suggested for each 1000 Calories provided above 3000. On the other hand it is recommended that even for adults whose energy need is less than 2000 Calories the thiamine allowance shall not be reduced below 1.0 milligram.

Thiamine nutrition of the elderly. Kirk and Chieffi (1949) found subnormal blood levels of thiamine in 10 per cent of the

adults over 40 that they examined (but in none of the younger adults); with some tendency for thiamine values to decrease with advancing age even among individuals "offered a diet adequate in vitamin B_1." The low thiamine blood levels were associated with clinical symptoms; and both were correctable in most cases by extra thiamine. Thus, even though it is not yet thoroughly understood why the elderly should require more thiamine or use it less efficiently than younger adults, it is clearly worthwhile to provide them with a liberal intake.

On certain low-thiamine diets and in some individuals there appears to occur a measurable synthesis of thiamine by the intestinal microorganisms; but whether this thiamine remains confined to the bacterial cells or can be absorbed and used by the host's body—and, if so, whether in sufficient amounts to have practical significance are still unknown. On the other hand, the possibility has been suggested (Kirk, 1951) that the intestinal microorganisms may under some conditions take up ingested thiamine, making it unavailable to the human host. (A similar effect was noted by Ness, *et al.* (1946) when live yeast was fed.) A series of papers in the Japanese literature (*Review* 1956) reports that bacteria found in the intestines of some individuals produce a *thiaminase*—a thiamine-destroying enzyme—which, it is suggested, may play a part in the development of beriberi. The interrelations of man and his intestinal flora will be seen to have a possible bearing on the economy of several of the B-complex vitamins.

Another factor which may condition the utilization of dietary thiamine is the presence in certain raw fish and shellfish of a thiaminase. Melnick and his associates (1945) found that ingestion of raw clams with meals could reduce the availability of thiamine for man by as much as 50 per cent. How important this effect may be will depend, of course, on the prominence of such raw seafood in the diet.

Stability of Thiamine in the Storage and Preparation of Foods

Mature, dry, unbroken seeds seem to contain their thiamine in a relatively stable form and favorable environment. In one published report, the evidence of local records was accepted as showing that wheat taken from the bottom of a certain dry granary com-

partment was a century old. On feeding to experimental animals it was found to be a potent source of thiamine. Obviously there was no means of knowing just how much thiamine it had originally contained; but obviously also the thiamine of this wheat had shown good stability.

Like other thermolabile substances thiamine is more stable to heating in a dry state than in solution.

Thiamine, like vitamin C, is (other conditions being equal) distinctly more stable in a moderately acid than in a correspondingly alkaline solution. In tomato juice, for instance, experiments at Columbia showed that the rate at which the destruction of thiamine occurred was gradually increased with rising temperature, while other work brought out clearly the destructive effect of additions of alkali on whichever side of the neutral point. In one series of experiments, heating was always at the natural acidity of the tomato juice (pH = 4.3). A 100° C., this heating destroyed 20 per cent of the original thiamine in 4 hours; at 110°, 33 per cent; at 120°, 47 per cent; and at 130°, 55 per cent. Clearly there is here no sudden destruction, or even sudden rise in the rate of destruction, at any definite temperature. The chemical reaction which changes the thiamine into something else is increased in its rate as the temperature rises, but no more so than most chemical reactions. Another study showed also a destruction of 20 per cent of the thiamine of tomato juice when heated 4 hours at its natural acidity; when the acidity was about half neutralized before heating, the destruction rose to 31 per cent; and when the juice had been brought barely over the neutral point (to pH 7.9) the destruction for the same time and temperature of heating was 70 per cent. Beadle, Greenwood, and Kraybill (1943), studying the destruction of thiamine in pure solutions, confirmed the effect of pH on destruction of thiamine, and found that this depended also on the kinds of salts present in the solution.

While thiamine and ascorbic acid thus show a similarity in their thermolability and susceptibility to alkali, we would not be justified in assuming from these facts similarity of behavior of vitamins in general; for Morgan has found that the impregnation of drying fruit with sulfurous acid diminishes the loss of vitamin C but increases the loss of thiamine.

A point of great practical importance is the finding that thiamine

in meat is very much more stable toward heat than when in aqueous solution. Thus Greenwood, *et al.* (1943), Lee, *et al.*, (1954), and others have found only about one-sixth of the thiamine to be destroyed in the cooking of pork. Products used in curing pork seemed to have no adverse effect on the heat stability of thiamine. A significant amount of thiamine passes, however, into the "drip" when frozen meats thaw, and into the drippings of roasted meat; so that these should be conserved and used.

In a study made by the U.S. Department of Agriculture, about 20 to 25 per cent of the thiamine of spinach, potatoes, and snap beans was destroyed when these vegetables were cooked by boiling, while additional amounts were dissolved away. Soda, added to preserve the green color of the snap beans, more than doubled the destruction of thiamine in cooking. Cooking carrots in boiling water or under steam pressure, and double-boiler cooking of rolled oats and whole wheat up to two hours, did not cause any measurable destruction of thiamine. Conditions commonly prevailing in large-scale cookery in public eating establishments are apt to cause very much greater losses in thiamine of vegetables than would be expected to occur in a well run home kitchen.

Baking losses as reported are now known to have been above the truth in some cases, because some of the methods used for determination of thiamine did not reveal the whole amount present in the baked product. In a special study made by the Food and Drug Administration and reported in the official hearings upon the proposed new standards for bread, the baking losses ranged from too little to measure up to about 15 per cent as a maximum, and averaged less than one-tenth of the thiamine originally present in the dough from which the bread was made.

Thiamine Contents of Typical Foods

Thiamine is of very widespread occurrence in the animal and vegetable kingdoms, and therefore in foods of both animal and plant origin unless these have been artificially refined or otherwise subjected to loss. Table 24 summarizes the average thiamine values of a number of typical foods, expressed as milligrams per 100 grams of edible portion, as milligrams of thiamine per 100 grams

TABLE 24. *Thiamine in Edible Portion of Typical Foods*

Food	*Thiamine: Milligrams per* 100 gm. food	100 gm. protein	2500 Calories	*Food*	*Thiamine: Milligrams per* 100 gm. food	100 gm. protein	2500 Calories
Apples	.04	13.3	1.7	Liver, beef	.26	1.3	4.8
Bananas	.04	3.3	1.1	pork	.40	2.0	7.5
Beans, dried	.67	3.1	5.0	Milk, whole	.04	1.4	1.5
green, string	.08	3.3	5.7	dry, non-fat solids	.35	1.0	2.4
Beef, medium fat	.08	0.4	0.8	Oatmeal	.60	4.2	3.8
Bread, enriched	.24	2.8	2.2	Oranges	.08	8.9	4.4
unenriched	.05	0.6	0.4	Peanut butter	.12	0.5	0.5
Broccoli	.10	3.0	8.6	Peas, green	.34	5.1	8.7
Cabbage	.06	4.3	6.2	Pork, medium fat	.74	4.9	5.4
Carrots	.06	5.0	3.6	Potatoes	.11	5.5	3.3
Chicken	.08	0.4	1.0	Rice, entire	.32	4.3	2.2
Eggs, whole	.10	0.8	1.5	white	.07	0.9	0.5
yolk	.27	1.7	1.9	converted	.20	2.6	1.4
white	tr.			Sweetpotatoes	.09	5.0	1.8
Fish	.05	0.3	1.6	Tomatoes	.06	6.0	7.5
Ham, smoked	.70	4.1	4.5	Wheat flour, whole	.55	4.1	4.1
Lamb	.16	0.9	1.7	white, unenriched	.06	0.6	0.4
Lettuce, headed or				white, enriched	.44	4.2	3.0
loose-leaf	.04	3.3	6.7	Wheat germ	2.05	8.1	14.2

of protein, and as milligrams of thiamine per 2500 Calories. The thiamine content of many more foods will be found in Table 47 of Appendix C, and of still others in *Agriculture Handbook No. 8* of the U.S. Department of Agriculture, from which the values in this book are taken.

Table 25 shows the relative contributions of some of the different food groups to the total thiamine of our national food supply, in a typical recent year, and in the period just before the Enrichment program mentioned in Chapter 9 became effective.

Meats exhibit a noteworthy species difference in that the average thiamine content of pork muscle greatly exceeds that of beef

muscle. The glandular organs, *kidney* and *liver*, and also *heart* show thiamine values intermediate between beef muscle and pork muscle. Meats, fish, and poultry together provide about one-fourth of the nation's thiamine (from foods).

The thiamine values of *milk* and *eggs* are not conspicuously high when considered on any of the bases of Table 24. However, when milk is used as liberally as (for several other nutritional reasons) is wise, it becomes an important source of thiamine in the dietary,

TABLE 25. *Relative Amounts of Thiamine from Various Food Groups in the Average American Dietary: 1935–39 Compared with 1952* (based on Supplement for 1949 to U.S. Department of Agriculture *Miscellaneous Publication No. 691* and on *Agricultural Statistics, 1953*)

	Before Enrichment Program		*After Enrichment Program*	
	Total thiamine: 1.43 mgm.		*Total thiamine: 1.92 mgm.*	
	% of total calories	*% of total thiamine*	*% of total calories*	*% of total thiamine*
Dairy products	11.5	12.7	13.4	10.8
Eggs	2.0	2.7	2.8	2.9
Meats, poultry, fish	10.7	25.2	12.8	23.4
Vegetables and fruits	10.1	28.6	9.4	18.8
Grain products	28.0	19.1	22.8	32.9
Dried peas and beans, nuts, soya flour	2.5	7.3	2.9	6.6

though this fact is often missed because of the high water content of milk.

Cereal grains and their milling and bakery products call for special attention, because while the seed as a whole is relatively rich in thiamine very much the largest part of this is rejected in the milling of refined wheat flour or rice. The replacement of the thiamine, so as to bring white flour and bread to something approaching a whole-wheat level *in this respect*, is now general under the Enrichment program. In the years before "enrichment," grain products provided less than one-fifth of the total national thiamine intake, while now they provide practically one-third (though our total use of grain products has decreased) (Table 25). The total

ımount of thiamine available in the national food supply has meanvhile risen from 1.43 to 1.92 milligrams of thiamine per person ɔer day.[1]

The legume seeds, *beans, lentils*, and *peas*, rank near or with the vhole-grain cereals as rich sources of thiamine, while *soybeans* ·xceed them. Even *fresh young green peas*, notwithstanding their ıigh water content, are as rich as whole rice.

The *other vegetables* and the *fruits* show fairly wide variations n thiamine content but all "carry their share" in the sense that their :hiamine content per 2500 Calories is at least as generous as the Recommended Allowances provide for the diet as a whole. Fruits ınd vegetables together account for nearly one-fifth of the thiamine in the nation's food supply. It is therefore a mistake to treat the succulent fruits and vegetables as if, containing only about one part per million of thiamine, they were nearly negligible sources. For, because of their succulent character (and relatively low calories) fresh, including frozen and cold-stored, fruits and vegetables can be consumed in liberal quantities with pleasure and without fear of making the dietary too fattening. Moreover, our newest knowledge of nutrition tells us even more clearly than did the "newer knowledge" of a few years ago, that liberal use of such fruits and vegetables is so advantageous to health and efficiency as to be especially good dietetics and food economics. A normal adult dietary which gives due recognition to present-day knowledge will very probably contain two to three pounds of total fruit-and-vegetables in the course of a day, and when used in such quantities the fruits and vegetables as a group are among the major sources of thiamine in the dietary. A more abundant use of fruits and vegetables, the selection varying with individual preference and with market supply and price, is certainly one of the very best ways of improving the dietary in several of its mineral and vitamin factors.

EXERCISES

1. Develop symptoms of thiamine deficiency in rats, pigeons, fowls, or chicks by means of a diet deficient in thiamine.

[1] Note that such figures on "*per capita* consumption" apply to foods *as purchased* and include no allowance for losses in cooking or other forms of wastage. In the case of such heat-labile factors as thiamine and vitamin C, the amounts which actually enter the body may be substantially less.

2. What is the thiamine content of each of the dietaries or weekly food orders which you have previously planned or recorded?

3. Arrange your "forty foods" in the order of their thiamine content: (*a*) per 100 grams of the edible portion; (*b*) per 100 Calories.

4. Which of the dietaries which you have previously studied provide as much thiamine as the Recommended Dietary Allowances?

5. What is the legal status of enrichment in the state where you live?

6. If not all white bread is compulsorily enriched, estimate, from inquiry and observation in bakery and grocery shops, what proportion of the breadstuffs sold in your community is enriched. What proportion is whole-grain?

7. If all the breadstuffs consumed were enriched or whole-grain, would you feel that no further thought need be given to either iron or thiamine in planning dietaries for normal people?

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RIBOFLAVIN, NIACIN (NICOTINIC ACID), AND THE PROBLEM OF PELLAGRA WITH ITS RELATED ILLS

Introductory Explanation

The science of nutrition of 1920 recognized vitamins A, B, and C. Since that time not only have several independent additions been made, but also there have been differentiations within the original concepts. Most especially is this true of vitamin B. We are not here concerned with questions as to how many members of the "B group of vitamins" there are, nor as to all the different designations and concepts that have been more or less current in the course of the evolution of our knowledge up to its present point. Rather, this chapter is devoted to two of the more heat-stable vitamins of the B group. Each of these is now a well recognized specific nutrient; both are involved in the problem of pellagra and its related ills. Hence they are included together in this chapter. First we shall study riboflavin, its significance in nutrition and its quantitative distribution in foods, in much the same way that we studied thiamine in the preceding chapter; then, somewhat more briefly, niacin (nicotinic acid); and, finally, the very important health problems of the prevention of pellagra and the other diseases in which shortages of one or both of these vitamins are involved.

RIBOFLAVIN

After yeast had been used for some years as an occasional experimental food in vitamin research, it was found to have a growth-promoting value (as an addition to certain laboratory diets) even

after it had been heated to destroy its thiamine. Evidently it contained something of nutritional significance which is more stable toward heat than thiamine is.

This relatively heat-stable (thermostable) something (called vitamin B_2 or vitamin G) was found also to be present, in relatively greater abundance than was thiamine, in milk; and likewise to a very significant extent in egg white, which showed only traces of thiamine.

It had long been known that milk contains besides the orange-yellow fat-soluble substance which goes into the butter or cheese, a greenish-yellow water-soluble natural coloring matter, which was first called *lactochrome*, and later *lactoflavin*.

At the same time that research in this country was developing the concept of a "vitamin B_2" or "vitamin G" as a nutritional factor, Warburg and Christian abroad separated from yeast a new oxidation enzyme which they called "yellow enzyme," and showed to consist of a protein fraction and a yellow pigment. Neither fraction alone was active enzymically, but both the protein component and the *prosthetic* or chemically active grouping (in this case, the yellow pigment) were required for the enzyme effect to occur. This yellow pigment, which was soon shown to be the same substance long known as lactochrome, now turned out to have nutritional effects agreeing with some of those of the "heat-stable fraction" of yeast. The explanation, or part of it, was found to be that the individual substance lactoflavin is one of the relatively heat-stable factors contained in yeast, in milk, and in some other foods.

After its complete chemical identification showed that the pentose sugar, *ribose*, was one moiety, the substance was renamed *riboflavin*.[1]

Riboflavin is widely distributed in both plant and animal tissues and is contained in relative abundance in milk and eggs, the means by which animals convey nutriment from one generation to the next. In this latter respect it may be considered the water-soluble analogue to the fat-soluble vitamin A.

[1] Similar compounds in which the sugar, however, is different, are named correspondingly: e.g., *lyxoflavin*, recently reported to occur in the human heart, in which the sugar is lyxose; and *galactoflavin*, used as a riboflavin antagonist, in which galactose replaces ribose.

Nutritional Functions of Riboflavin

The best known function of riboflavin is that it combines with phosphoric acid and protein to form tissue respiratory enzymes which are importantly involved in the life processes of probably all active tissues. The tissues tend to retain these *flavoprotein* enzymes tenaciously under dietary deprivation, but after an extended period on a riboflavin-poor diet, the concentration of these enzymes decreases significantly, undoubtedly with resulting deterioration of tissue function. This deterioration is widespread, and the particular manifestation which is most conspicuous may vary from species to species and from individual to individual depending on the circumstances.

Considering the importance of the flavoprotein compounds, it is not surprising to find many evidences of a close interrelationship between riboflavin and protein in metabolism. Thus, for example, liberal riboflavin intake favors effective protein utilization, while in riboflavin deficiency high protein levels are poorly tolerated. Stresses and shocks which occasion severe protein loss from the body are said to bring attending riboflavin loss, and in rebuilding body protein after such episodes, riboflavin is of critical importance.

Several investigators have reported that riboflavin deficiency lowers the resistance of experimental animals to certain diseases; and the *Journal of the American Medical Association* has spoken of riboflavin as being "necessary for the maintenance of the defense powers of the organism."

Riboflavin is an important factor in successful reproduction. Thus, in experiments by Ellis and others at Columbia, increases in riboflavin intake which had no detectable effect on health and well-being of the mothers were nevertheless reflected in superior vigor of the offspring; while others have shown (see, for example, Warkany and Schraffenberger, 1944) that female rats on riboflavin-deficient diets are apt to bear young with abnormal bony structure and other defects.

Long-Term Experiments. In long-term experiments with rats it has been found that riboflavin is essential both to growth and to normal nutrition at all ages. When the food is poor in riboflavin

for any considerable length of time, digestive disturbances, nervous depression and nerve degeneration (different from the polyneuritis of thiamine deficiency), general weakness and lowering of tone, and an unwholesome condition of the skin with or without eye trouble, are apt to develop; the incidence of infectious disease is likely to be increased, vitality diminished, life shortened, and the prime of life curtailed by the unduly early onset of the aging process.

The positive effects of a riboflavin intake more liberal than is necessary to prevent symptoms of shortage are challenging. As we have seen in earlier Chapters, there are some nutrients regarding which our scientific knowledge agrees with the old adage that "enough is as good as a feast." Probably most students of nutrition would agree that fat, sugar, table salt, and cholesterol among other things may be thus regarded. In fact it has sometimes been taught as a principle that one can use to advantage only a small, if any, margin of nutriment above what one actually needs. But recent research has shown that there are other nutrients of which increased intakes continue to bring additional benefits, up to levels much above those which are demonstrably necessary as shown by the data of relatively short-time experiments. Among the nutrients thus possessed of potentialities for importantly constructive improvement of nutritional status above the levels obviously needed for normal results or as McCollum puts it, cases in which there are, or may be, important differences between minimal-adequate and optimal nutrition—are calcium, vitamins A and C, and riboflavin. For experiments by Ellis and others with rat families which (with a uniform hereditary background and with environmental factors alike in all other respects) have been fed for two or more generations on dietaries of different riboflavin content, have shown that *when account is taken of the full-life and successive-generation effects, increasing benefits continue to result from increasing richness of the dictary in riboflavin, up to intake levels more than twice as high as that of minimal adequacy.*

There is strong scientific probability that the effects of higher or lower riboflavin intake upon the life history will be similar in their general trend and significance in the human family to those observed in the rat families.

Relation to Human Nutrition

Late in 1938 riboflavin deficiency was produced experimentally as a human deficiency disease (*ariboflavinosis*) by Sebrell and Butler; and soon many cases of it were recognized in the clinics, some occurring independently and some in conjunction with pellagra.

Cheilosis (cracking of the lips at the corners of the mouth) and *vascularization of the cornea* are two definitely located lesions for which shortage of riboflavin appears to be, while not the sole, perhaps the most usual cause, and which have been repeatedly observed in people of various ages.

Spies and coworkers have reported riboflavin deficiency as probably the most frequent of dietary diseases in the child population with which they worked in the South, and the investigations of the Milbank Memorial Fund indicate a rather high incidence in New York City also, at least in low-income groups.

Very interesting were the cases found among members of a Southern hospital staff by Sydenstricker and coworkers (1940). These people chose their food at will from a satisfactorily supplied table and would not have been considered in any danger of nutritional deficiency, but on hearing that the research physicians were interested in cracked lips and "eyestrain" they offered themselves for examination and were found to show typical symptoms of shortage of riboflavin. The investigators considered that dietary neglect of milk, eggs, and green vegetables (although these were offered in the daily fare) was the cause of the riboflavin deficiency in these cases. Undoubtedly dietaries similarly poor in riboflavin are taken by very large numbers of other people because of poverty. Dr. Wilder has spoken of having met the folklore expression "poor folks' mouth" as a name for the cheilosis now recognized as a symptom of riboflavin deficiency.

China, India, and Africa have all reported areas of high incidence of human riboflavin deficiency.

In the United States probably the majority of cases of human riboflavin deficiencies either: (1) are in people who are simultaneously subjects of some other deficiency as well and are cured and recorded as pellagrins; or (2) are subclinical and go unrecognized,

though lowering the health-plane, efficiency, and earning power of the victims.

Another reason for uncertainty, as to how prevalent riboflavin deficiency (ariboflavinosis) is in this country, lies in the fact that there may be other causes also for some of the conditions first attributed to shortage of this vitamin.

Inasmuch as this book seeks to serve in the field of health rather than of pathology, it is appropriate to emphasize here that, whatever may be the exact relation of this vitamin to one or another specific disease, there is no doubt that riboflavin is a very important factor in health. And this is true both for health as freedom from disease and for the upbuilding and maintenance of that higher health which is rightly regarded as a positive quality of life.

Investigations of riboflavin requirement in man have indicated that clinical evidence of deficiency occurs when the intake is less than 0.6 milligram per day in an adult. On the other hand, urinary excretion tests somewhat like the "saturation" tests described for ascorbic acid, suggest that an intake of 1.1 to 1.6 milligrams is necessary to insure adequate body stores of riboflavin in normal adults; while the corresponding value in pregnancy is about 2.0 milligrams. Studies by Holt and his associates on infants suggest that they have a large riboflavin requirement relative to adults: 0.4 to 0.5 milligram being required to maintain tissue stores (as judged from excretion data) in infants weighing 10 to 15 pounds.

Although pointing out that "A direct relationship between riboflavin and protein requirements has not been established," the Food and Nutrition Board of the National Research Council in their 1953 revision of the *Recommended Dietary Allowances* has based the riboflavin allowances on the protein allowances, multiplying the latter (in grams) by 0.025 to compute the former (in milligrams). For the fairly active man of average size, the recommended allowance is 1.6 milligrams of riboflavin per day; for women, 1.4 milligrams, increasing to 2.0 milligrams in the latter part of pregnancy and 2.5 milligrams in lactation. For infants under one year, the allowances range from 0.4 to 0.9 milligram; children 1 to 9 years old, 1.0 to 1.5 milligrams; older boys, 1.8 to 2.5 milligrams; and older girls, 1.8 to 2.0 milligrams per day. For the specific recommendations at various ages the complete table in the Appendix should be consulted.

As in the case of thiamine, riboflavin seems to be synthesized by the intestinal microorganisms at least under certain conditions; but the amount of such synthesis and the extent to which riboflavin so formed enters into the service of the body, are still not well defined.

As already briefly noted, much well controlled animal experimentation with species which are known to resemble the human in the nature of their nutrition processes has clearly shown the long-term superiority of liberal intakes of riboflavin over intakes fashioned closely upon relatively short-term concepts of minimal adequacy. The more liberal intakes result in superior performances both in complete individual and family life histories and in respect to efficiency in meeting particular stresses.

Though we cannot expect to translate the findings on one species directly into precise quantitative recommendations for another species, it would appear that the general level of the Recommended Allowances corresponds to the minimal edge of the approximately optimal zone as indicated by the original or "first generation" animals in the Columbia experiments—those receiving the assigned diet from infancy till natural death. When the offspring of such experimental families were continued on the respective family dietaries the objective records of performance indicate (as noted earlier) that optimal performance in the successive-generation type of test required a still higher level of riboflavin intake.

Thus there is here a general finding that the long-term type of research with objective evidence through entire lifetimes and into successive generations shows that riboflavin carries the potentiality of larger benefits than are fully revealed by experiments covering only short segments of the life cycle.

As one studies the literature of nutrition of the past hundred years in the light of the knowledge of riboflavin gained in the past few years, and remembers that meat, eggs, and milk are all relatively rich in riboflavin, one is apt, if sufficiently openminded, to recognize a growing probability that riboflavin may have been responsible for a significant share of the all-round bodily benefit which has been traditionally attributed to liberal intake of "animal protein." Beneficial results from dietary changes which increase our consumption of milk, eggs, and meat are apt to be attributed to increased intake of "animal" or "first class" protein, whereas actually they may be due in greater degree to extra riboflavin than to

extra protein. For the estimates of food consumption in the United States both those obtained from studies of family food consumption and those which begin with statistics of food production and follow them through to "disappearance in channels of human food consumption at the retail level" indicate that we habitually consume a considerably larger surplus of protein than of riboflavin, relative to our nutritional needs. Also worth keeping in mind is the evidence that the body can utilize protein to greater advantage when the dietary at the same time supplies liberal amounts of riboflavin, of calcium, or of both calcium and riboflavin.

Foods as Sources of Riboflavin

Plants form riboflavin beginning early in their lives. Even very young plants contain more riboflavin (in actual amount or in percentage of their dry matter) than the seeds from which they sprouted.

Somewhat as with vitamin C, though perhaps in a lesser degree, the young, juicy stage of development at which we most relish succulent foods for their "freshness" is also that at which they are best as sources of riboflavin. In general, too, the most actively functioning parts of the plant, the green leaves and growing tips, are relatively richest in riboflavin.

The riboflavin contents of a number of typical foods are shown in Table 26, expressed on the same bases as are the corresponding thiamine values in Table 24 (preceding chapter).

Perhaps the most important general differences in the quantitative distribution of these two vitamins are, that milk is relatively richer in riboflavin while wheat is relatively richer in thiamine, as are probably most of the seeds.

The green leaf foods, represented in Table 26 by kale, are also richer sources of riboflavin than of thiamine. Of the riboflavin content of fruits and vegetables generally we may say much the same as of their thiamine content, namely, that if the figures look low it is largely because of the high water content of these foods, and that when used as abundantly as they well may be, they become good sources.

Beef and pork muscle, which will be remembered as differing in thiamine content, are seen to be very similar in the amounts of

TABLE 26. *Riboflavin in Edible Portion of Typical Foods*

Food	*Riboflavin: Milligrams per* 100 gm. food	100 gm. protein	2500 Calories	*Food*	*Riboflavin: Milligrams per* 100 gm. food	100 gm. protein	2500 Calories
Bananas	.05	4.2	1.4	Lettuce, headed or			
Beans, dried	.23	1.1	1.1	loose-leaf	.08	6.7	13.3
green, string	.11	4.6	7.9	Liver	3.33	16.9	61.2
Beef, medium fat	.16	0.9	1.7	Milk, whole	.17	4.9	6.2
Bread, enriched	.15	1.8	1.4	dry, non-fat	1.96	5.5	13.5
unenriched	.11*	1.3	1.0	Oatmeal	.14	1.0	0.9
Broccoli	.21	6.4	18.1	Oranges	.03	3.3	1.7
Cabbage	.05	3.6	5.2	Peanut butter	.13	0.5	0.6
Carrots	.06	5.0	3.5	Peas, green	.16	2.3	4.0
Cheese, Cheddar	.42	1.7	2.6	Pork, medium fat	.18	1.2	1.3
cottage	.31	1.6	8.2	Potatoes	.04	2.0	1.2
Chicken	.16	0.8	2.0	Rice, white	.03	0.4	0.2
Eggs, whole	.29	2.3	4.5	Sweetpotatoes	.05	2.8	1.0
yolk	.35	2.1	2.4	Tomatoes	.04	4.0	5.0
white	.26	2.4	13.0	Wheat flour, whole	.12	0.9	0.9
Fish	.08	0.4	2.5	white, unenriched	.05	0.5	0.3
Ice cream	.19	4.8	2.3	white, enriched	.26	2.5	1.8
Kale	.26	6.7	16.2	Wheat germ	.80	3.2	5.5
Lamb	.22	1.2	2.3				

* Varies with percentage of milk solids. Figures given are for bread with 4 per cent milk solids.

riboflavin which they contain. Remembering that the Recommended Allowances provide 2.5 milligrams of riboflavin for each 100 grams of protein, we see that muscle meats are relatively richer sources of protein than of riboflavin. Liver contains, weight for weight, nearly twenty times as much riboflavin as does muscle; and kidney is about two-thirds as rich, in riboflavin, as is liver.

Milk, notwithstanding its high water content, contains just about as much riboflavin, weight for weight, as do the muscle meats. A quart of milk thus furnishes about as much riboflavin as two pounds of clear lean meat. Relative to its protein content, milk is a far richer source of riboflavin than muscle meats.

Both cheese and whey are good sources. This is because an important part of the riboflavin of milk is "free" and goes into the whey, while another important part is so combined with protein as to stay in the curd in cheese making.

Eggs are distinctly richer in riboflavin than are the muscle meats. Even egg white, which contains only traces of thiamine, is a relatively rich source of riboflavin, though the yolk is still richer.

Among the vegetables and fruits the green leaves are outstanding; and, in general, those vegetables which are really green are richer sources than vegetables which are not, and than fruits.

Whole wheat contains only about one-fourth as much riboflavin as thiamine. The germ or embryo is richer in both of these factors than is the entire grain. But as the germ constitutes only about two per cent of the weight of the grain, a large fraction of both thiamine and riboflavin is rejected with the bran, even if the germ is retained with (or returned to) the white flour.

Riboflavin is one of the substances added in the enrichment of bread and flour; but, though the riboflavin level of enriched bread is thus brought up to the level of wholewheat bread, the enriched product still carries barely its proportionate share, relative to its calorie content, and less than its proportionate share, relative to its protein, of the amounts recommended in the total dietary. Thus, as shown in Table 27, though the enrichment program has resulted in a definite increase in the proportion of the total riboflavin which comes from the grain products, these products still provide only about one-seventh of the total riboflavin in the average American dietary. The additional amounts of riboflavin which enrichment (at the present level) brings to the diet thus are of less significance relative to the total need for this factor than are the amounts of iron and thiamine added in enrichment. (See also Figure 30 in Chapter 19.)

By far the most important contributor of riboflavin to the national diet is milk (with its products other than butter), which supplies nearly one-half of the total. Next come meats, poultry, and fish; and grain products; followed by fruits and vegetables.

Stability of riboflavin. We have seen that riboflavin was differentiated from thiamine in the early studies by its relative stability to heat. The *destruction* of riboflavin by ordinary cooking procedures is generally not as great as that of thiamine, though addi-

TABLE 27. *Relative Amounts of Riboflavin and Niacin from Various Food Groups in the Average American Dietary: 1935–39 Compared with 1952* (based on Supplement for 1949 to U.S. Department of Agriculture *Miscellaneous Publication No. 691* and on *Agricultural Statistics, 1953*)

	Before enrichment program			*After enrichment program*		
	Total riboflavin: 1.86 mgm. *Total niacin: 15.2 mgm.*			*Total riboflavin: 2.34 mgm.* *Total niacin: 19.7 mgm.*		
	percentage of total			*percentage of total*		
	calories	*riboflavin*	*niacin*	*calories*	*riboflavin*	*niacin*
Dairy products	11.5	51.0	3.9	13.4	46.1	3.3
Eggs	2.0	6.2	0.2	2.8	7.0	0.2
Meats, poultry, fish	10.7	17.1	45.8	12.8	16.1	43.4
Vegetables and fruits	10.1	14.8	22.9	9.4	11.7	17.4
Grain products	28.0	6.2	16.2	22.8	15.0	26.2
Dried peas and beans nuts, soya flour	2.5	2.1	7.4	2.9	2.0	6.6

tional losses may occur in drippings of meat and in cooking waters if these are discarded. Probably much more significant is the destruction of riboflavin which may result from exposure to ordinary sunlight. This can be serious in the case of milk in glass bottles unless proper precautions are taken to protect the bottles from light. Thus, while the losses of riboflavin in milk during pasteurization, irradiation with ultraviolet light to increase vitamin D content, and exposure to ordinary light during bottling generally total 10 to 20 per cent of the original content, as much as two-thirds of the riboflavin remaining may subsequently be lost if the bottled milk is allowed to stand several hours in the bright sunlight. As a practical measure to conserve the riboflavin of milk, apparently the most important factor is to see that milk bottles are not allowed to stand in the light outside the house after delivery. Some loss of riboflavin may occur when other foods are exposed to light for long periods of time. Thus it was reported[2] that enriched white bread wrapped in opaque paper retained 30 to 60 per cent more riboflavin than bread wrapped in cellophane after maximum probable exposure to dif-

[2] *Journal of the American Dietetic Association,* volume **31**, p. 793 (1955).

fuse daylight and/or fluorescent light under normal conditions of commercial distribution.

NIACIN

The word *pellagra* signifies rough or inflamed skin. This is the outstanding symptom of a disease usually associated with poverty and with too great a dependence upon maize as a food.

The pellagrin, as the victim of this disease is often called, usually suffers not only with the skin trouble which gives rise to the name but also with mental or nervous disorders or depression, and with inflammation of the tongue and the lining of the mouth often extending to severe disorder of the digestive tract. One sometimes hears reference to "the three D's of pellagra—depression, dermatitis, and diarrhea." It is also considered by physicians in pellagrous regions that when either the nervous (mental) disturbance or the digestive disorder occurs with the characteristic dermatitis, the two symptoms together justify a diagnosis of the disease. A characteristic feature of the dermatitis of pellagra is that it occurs symmetrically upon, for instance, the backs of the hands, the ankles, the forearms, or the back of the neck. Often but not always, the dermatitis is most pronounced on some part of the body which is exposed to the sun. In its early stages it may resemble sunburn.

Not until the first decade of this century was pellagra reported in the United States. Then the reports of its presence rapidly grew to an alarming frequency, especially in the South. Authorities of the United States Public Health Service consider that probably over 100,000 of our people suffered from pellagra in each of several years.

Naturally, this disease has been much studied. It was found that an analogous condition, called "blacktongue," in dogs could be induced experimentally by pellagra-producing diet, and cured by such dietary improvements as were found to cure clinical pellagra.

Late in 1937, Elvehjem found that niacin (nicotinic acid) or its amide cures blacktongue, and immediately there followed a rapid succession of reports of its successful use in human pellagra, though this does not necessarily mean the entire cure of the pellagrin, as will be explained more fully below.

Like riboflavin and thiamine, niacin has been found to function

importantly as a component of tissue enzyme systems. Thus, niacinamide is a component of the factors known as Coenzyme I and Coenzyme II, which function in many biological oxidations, especially of carbohydrate.

Relation to Human Nutritional Needs

Several substances related to niacin are normally excreted in the urine, and attempts have been made to assess the nutritional status of individuals by determining the excretion of these substances. The interpretation of the results so as to estimate the dietary requirement appears uncertain for a number of complicating reasons. One fact which confuses the interpretation is the ability of the body to form niacin from the amino acid tryptophan. Without attempting to define the exact quantitative relations of the change and the extent to which it occurs, it is nevertheless clear from the work of Goldsmith and others that pellagra in man can be treated with tryptophan. The earlier observed failure of close agreement between the niacin content of certain foods and their pellagra-preventive value as established in the clinic finds at least a partial explanation in this ability of tryptophan to serve as a precursor of niacin. And the fact that maize is poor not only in niacin but also in tryptophan (as compared, for example, with wheat) may help to explain the long established association of pellagra with a maize diet.

	Niacin	*Tryptophan*
Whole wheat	4.3 mgm./100 gm.	168 mgm./100 gm.
Whole maize	2.0 " "	55 " "

Goldsmith and her associates found that when the diet supplied about 190 milligrams of tryptophan per day, 4 to 5 milligrams of dietary niacin was insufficient to prevent pellagra, while 7 milligrams of dietary niacin was protective. The urinary excretion of niacin end-products was studied as the niacin intake was gradually increased and was found to rise sharply when the intake reached 8 to 10 milligrams daily. The findings suggest that this latter intake provides adequate body stores of niacin under the conditions of this study, viz., on a corn diet furnishing about 200 milligrams of trypto-

phan daily. To the extent that this level of tryptophan intake is distinctly lower than on ordinary American diets, one may regard the niacin need found under the conditions of these experiments to be higher than would have obtained on a more usual (more generous) tryptophan intake. In any event, it may be said of the *Recommended Dietary Allowances* for niacin, which are set at *ten times the thiamine allowances* throughout: first, that they rest upon less clearcut evidence of human need than is the case with most of the factors included in the table; and second, that, at the points on which there is direct evidence, the recommended allowances seem to provide a large margin of safety even without taking account of the niacin potentially obtainable from the dietary tryptophan. Intestinal synthesis may also play a part in meeting the need for niacin.

In view of the tentative nature of our present knowledge of desirable levels of intake of niacin and the relation of these to the tryptophan intake, no table of niacin values of foods is included in this chapter (although such information may be found in the Appendix). Table 27 serves to summarize the relative importance of the different food groups as contributors of niacin to the diet, and to show how this has been affected by the Enrichment Program, which stipulates the addition of niacin, as well as of iron, thiamine, and riboflavin, to refined cereal products. The outstanding food source of niacin in the national dietary is the group of meats, poultry, and fish; with grain products far behind in second place (since enrichment), and fruits and vegetables third.

THE PRACTICAL PREVENTION OF PELLAGRA AND RELATED ILLS

Recent clinical evidence seems to leave no doubt that while niacin (nicotinic acid) cures the most outstanding symptoms of pellagra, the typical pellagrin is usually a sufferer from shortage not only of niacin but also of riboflavin.

Thus while riboflavin cannot prevent or cure pellagra without niacin, yet in practice the riboflavin content and the niacin content of the diet both have a bearing upon the occurrence and persistence of the disease. Liver and yeast, being relatively rich in both, naturally have a high place in therapeutic discussions of the disease. But

such permanent and widespread reform of the food supply as is needed will probably be more effectively brought about in terms of the more staple or everyday foods of the general population.

The typical diet of the poor pellagrin consists so largely of pork fat, corn bread, soda biscuits, and syrup that it cannot be made nutritionally good by the addition of niacin alone. Even with liberal niacin and thiamine it would also need fruits, vegetables, and milk in some form to increase its content of calcium, vitamins A and C, and riboflavin, and possibly also to improve the character of its protein mixture. It is also to be kept in mind that enriched flour and bread carry only "their share" of certain nutrients and do not solve the problem of adequate nutrition.

In 1932, careful studies of food supplies and dietary practices in relation to the occurrence of pellagra were made with Florida families by Sandels and Grady, and with South Carolina families by Stiebeling and Munsell. In both states it was found that the families successful in warding off pellagra used dietaries containing a much higher proportion of milk than did the families in which one or more cases of pellagra occurred. Sandels and Grady further found a significantly larger consumption of succulent vegetables, and indications of a larger use of eggs, cheese, and fruit in the families which escaped pellagra.

Combining findings of the U.S. Department of Agriculture and of the U.S. Public Health Service, it appears that any one of the following in the daily dietary is nearly always effective for prevention of pellagra: a quart of milk or buttermilk; a pint of evaporated milk; one-third to one-half pound of dried skim milk, of lean meat, of fresh or canned collards, kale, green peas, or turnip greens; or two to three pounds of tomatoes, fresh, canned, or as juice.

Pellagra-preventing campaigns in the South have emphasized the home production of vegetables and the keeping of cows and chickens. An effective combination of pellagra-prevention and nutrition education was found by the Red Cross in the plan of lending a cow to the poor country family until better health and resultant increased earnings made it possible for the family to buy one.

At the same time, dietaries generally have had their thiamine, riboflavin, and niacin contents increased automatically by the enrichment of refined wheat products and (in many parts of the South) of refined maize products also.

What Other B-Vitamins Are Likely to Be Limiting Factors in Human Health?

In our opinion it is too early to attempt an explicit answer to this question; and too late to ignore it. The next chapter aims to supply starting points for those desiring to study the question.

EXERCISES

1. Arrange your "forty foods" in the order of their riboflavin content, (*a*) per 100 grams of edible portion, and (*b*) per 100 Calories.

2. On the above showing, and taking food costs into account, which of these foods would you consider of most practical importance for increasing the dietary intake of riboflavin?

3. Which of these foods are important sources: (*a*) of riboflavin and calcium; (*b*) of riboflavin and vitamin C; (*c*) of riboflavin and vitamin A value?

4. Taking account of the quantities in which they enter into well-balanced dietaries, (*a*) what familiar foods rival milk in importance as sources of protein, calcium, and riboflavin? (*b*) and which foods rival oranges in importance as sources of vitamin C and riboflavin?

5. Explain to what extent you have, in answering the preceding question, taken account of the potential as well as the present place of oranges in the food supply. What can you tell of the trend of citrus fruit production and prices?

6. Consult the most recent and authoritative medical publications available, as to whether the word pellagra now stands (*a*) for niacin deficiency *simply*, with any accompanying riboflavin deficiency regarded merely as an accidental complication, or (*b*) for the "complete clinical picture" for which it has hitherto stood, in which, while niacin controls the more outstanding symptoms, riboflavin is also a factor in the prevention and cure of the disease, and still other factors may be involved.

7. What is the present view as to the frequency of occurrence of riboflavin-deficiency as distinct from pellagra?

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14

OTHER WATER-SOLUBLE VITAMINS

Vitamin B_6 (Pyridoxine, Pyridoxamine, Pyridoxal)

Fairly early in studies on the differentiation of the "B-complex" vitamins, a very striking ("acrodynia-like") dermatitis was produced experimentally in rats, and the active ingredient of preparations which cured or prevented the condition was designated as "vitamin B_6." In 1939, a substance which was called *pyridoxine* was shown to have the properties of vitamin B_6, and for a time the two terms were used synonymously. Then two other distinct, though chemically related substances, designated, respectively, as *pyridoxamine* and *pyridoxal*, were found to have vitamin B_6 activity and to be the predominant forms in animal nutrition. Hence, there is now a tendency to prefer the term "vitamin B_6" where the whole group of active substances is meant, and to reserve pyridoxine as the designation of one specific chemical substance.

Vitamin B_6, largely as *pyridoxal phosphate*, is importantly involved in many biological enzyme systems, in particular those having to do with the metabolism of proteins and amino acids. It appears to function as coenzyme or prosthetic group in:

(1) the decarboxylation of amino acids;
(2) the transamination of amino acids;
(3) the metabolism of tryptophan and its degradation products, including the conversion of tryptophan to niacin; and
(4) various other processes involving amino acids, such as the removal of the sulfhydryl (– SH) group from cysteine and the cleavage of β-hydroxy-α-amino acids to glycine and aldehydes.

The symptoms most prominent in vitamin B_6-deficiency vary somewhat from species to species, but include:

(1) failure of growth in all young animals;
(2) dermatitis, often designated as *acrodynia* or *acrodynia-like*;

(3) convulsive or epileptoid seizures;
(4) microcytic, hypochromic anemia;
(5) sclerotic lesions of the arteries;
(6) failure of normal fat deposition and other disturbances of fat (or essential fatty acid) metabolism;
(7) endocrine disturbances;
(8) failure of normal antibody response.

To what extent these conditions result from upsets in the amino acid metabolism (occasioned by the role of vitamin B_6 in the enzymic reactions listed above), and to what extent they represent other aspects of biochemical function of vitamin B_6 are not yet clear.

In a recent study by Beaton, McHenry, and coworkers (1954) of the chronological sequence in which biochemical defects develop in the vitamin B_6-deprived rat, it was noted that the failure of growth was primarily a *failure of fat formation*, and that this occurred much earlier than any disturbance of protein or amino acid metabolism, leading the authors to suggest that "disturbances in nitrogen metabolism in the vitamin B_6-deficient rat may be secondary to a primary effect on energy production which deprives the animal of surplus food for storage as fat." Others (Fried and Lardy, 1955) have offered a different interpretation, suggesting that the dietary protein in the Toronto workers' experiment provided for normal protein deposition in growth, but that the vitamin B_6-deficiency, through its effect on the metabolism of amino acids, especially transamination, "would deprive the rat of a readily available reserve for fat and carbohydrate synthesis. To maintain its normal metabolism the vitamin B_6-deficient rat must call upon its fat reserves and hence these may be kept low."

Attempts have been made to relieve a variety of human disorders with vitamin B_6, in some cases with reported beneficial results but seldom under such controlled conditions as to establish that a deficiency of vitamin B_6 was actually the underlying fault. The nausea of pregnancy is one condition in which vitamin B_6 treatment has been widely used, but on the effectiveness of which medical opinion is still divided.

Efforts to induce vitamin B_6-deficiency experimentally in man by dietary restriction alone have generally met with, at best, limited success, perhaps partly because intestinal synthesis apparently supplies considerable amounts of this vitamin,[1] perhaps also because

[1] Marquez and Reynolds (1955) and Turner and Reynolds (1955) recently

relatively long periods are required to deplete the tissue stores. Symptoms can, however, be provoked on a low vitamin B_6 diet by feeding an antagonist of the vitamin, known as *desoxypyridoxine*. An *antimetabolite* or *antagonist* is a nutritionally ineffective compound so closely related in chemical nature to an essential metabolite that it tends to replace it in biological systems, bringing about a "conditioned deficiency" of the metabolite. Thus, desoxypyridoxine, as the name suggests, differs from pyridoxine in having one less oxygen atom. When it is fed to human beings on a vitamin B_6-low diet, symptoms develop that are alleviated by feeding additional pyridoxine, and which in this sense appear to be symptoms of vitamin B_6 deficiency. These include "superficial scaling, oily reddened skin lesions, especially around the eyes, nose, and mouth, fissures at the angles of the mouth and lateral canthi of the eyes, sore, swollen, red tongues and buccal mucous membranes . . . A few subjects developed signs of severe sensory neuritis, with numbness, hyperesthesia, and impairment of vibration and position sense. Increased excretion of xanthurenic acid following a test dose of tryptophan was observed in nearly all of the patients. Common subjective symptoms of deficiency included anorexia, nausea, vomiting, lethargy, somnolence and confusion." (*Present Knowledge in Nutrition*, Revised 1956, pages 99–100.)

A number of cases of nervous irritability and convulsive seizures in human infants fed a certain proprietary liquid canned milk proved to be symptoms of vitamin B_6-deficiency resulting from loss of this factor in processing. The condition was curable with dramatic promptness by feeding or injection of vitamin B_6. The milk product had been subjected to high-temperature sterilization with resultant loss of a large proportion of the pyridoxal and pyridoxamine originally present. When the product was reenforced before heat treatment with pyridoxine, which is much more heat-stable than the other two forms, sufficient vitamin B_6 remained in the final product to support normal nutrition in young infants.[2]

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reported that the total excretion of vitamin B_6 and its metabolites by normal non-pregnant and pregnant women on unrestricted diets exceeded the intake of vitamin B_6 by several times, thus suggesting synthesis of this factor, either in the intestinal tract or elsewhere in the body.

[2] It was estimated that the critical pyridoxine level for infants is between 50 and 80 micrograms per day.

Our knowledge as to the quantitative needs of human adults for vitamin B_6 is still poorly defined, as is the role, if any, of intestinal microorganisms in meeting this need.

Folic Acid Group: Folic Acid (Folacin, Pteroylglutamic Acid) and Its Conjugates; Folinic Acid (Citrovorum Factor); and Related Compounds

Day, Langston and coworkers found that monkeys require, for the maintenance of a normal condition of their blood, something that is contained in yeast and had not been chemically identified. In recognition of the part played by the monkey in assisting this discovery they called the substance vitamin M. Through much research by workers in different laboratories employing different organisms it finally appeared that what met the need of the monkey (vitamin M), of the chick (vitamin B_c), found in leaves (folic acid), and also a nutrient factor named for a species of bacteria, were all the same thing—a group of substances known chemically as pteroylglutamates.

The group of active substances includes pteroylglutamic acid (folic acid, folacin), which contains only one glutamic acid radical in the molecule; at least two naturally occurring active conjugates, pteroyltriglutamic acid (with three) and pteroylheptaglutamic acid (with seven glutamic acid radicals); folinic acid or citrovorum factor (a substance chemically related to folic acid and apparently formed from it in the body); and doubtless other forms.

One or more of the group are involved as coenzymes in metabolic processes involving the transfer of formyl (and related one-carbon groups) into and out of compounds. One system affected is the synthesis of purines and pyrimidines which go into the building of nucleic acids and as such are essential to all living cells.

Some species of animals require a dietary source of folic acid while others (like the rat) seem normally to obtain enough, through synthesis by intestinal microorganisms,[3] except when this process is suppressed as by feeding sulfa compounds and/or when a metabolic antagonist is administered. The development of anemia

[3] Studies by Luckey, *et al.* (1955) on germ-free rats indicate that some synthesis of the folic acid group occurs also in body tissues of the rat.

in folic acid-deficient monkeys has already been mentioned as playing a part in the discovery of this factor. Similar anemias are known in man (e.g., certain types of *sprue*, and socalled *nutritional macrocytic anemia*), usually associated with poor dietary habits, and which respond to treatment with folacin. Certain other megaloblastic anemias, in infants and pregnant women, also respond to folacin. To what extent the cause of such anemias is dietary, cannot be judged with certainty; yet such cases afford evidence that folic acid and related compounds do play an essential role in human metabolic processes.

There is reason to think that folic acid is normally synthesized to a considerable extent by intestinal microorganisms in man and this fact complicates the setting of dietary recommendations for this factor. Yet, as commented in the discussion accompanying the National Research Council's *Recommended Dietary Allowances* (1948), "the incidence of clinical deficiencies . . . affords evidence that intestinal synthesis should not be relied upon as a source of this nutrient." The 1953 revision of the *Recommended Dietary Allowances* remarks further that "it seems probable that dietary intakes of the order of less than a milligram per day can be expected to cover any nutritional needs for folic acid activity. The actual requirement or allowance cannot be set at this time."

Assessing the folic acid activity of foods presents on the one hand the difficulty of liberating all the folic acid from conjugate forms so that the test organisms can utilize it; and on the other hand the problem of how completely man can utilize such forms. It appears that some foods contain substances which affect the efficiency with which the body can utilize conjugates. Thus discrimination is needed in attempting to equate figures for "total folic acid" in foods to estimates of "folic acid requirement." But, as already noted, we seem to carry a measure of insurance in our normal intestinal flora.

Studies in experimental animals have indicated that even a short period of induced folic acid deficiency at a critical point in pregnancy results in a high percentage of abnormal young or fetal deaths (see Nelson, *et al.*, 1955).

With vitamin B_6 and pantothenic acid, folic acid appears to play a central role in antibody formation (see Axelrod, 1952).

In some aspects of its functioning, the folic acid group appears

to be related to tyrosine and to ascorbic acid; and, as noted in Chapter 9, folic acid and vitamin B_{12} are interrelated in their actions in ways not yet clearly understood.

References are included in the Suggested Readings to the clinical use of folic acid antagonists in the temporary control of leukemia, especially in children, a matter beyond the scope of a nutrition text.

Vitamin B_{12} (Cobalamin)

In 1948, investigators in this country and in England isolated pink cobalt-containing crystals from liver, which were introduced as vitamin B_{12}. Within a short time this substance was shown to be identical with a number of differently named factors whose existence had been recognized in diverse studies. Thus, as already noted in Chapter 9, vitamin B_{12} was established as the *anti-pernicious anemia factor*. Seven years after its isolation, its chemical identification was completed (see *Nutrition Reviews*, vol. 14, p. 64, 1956). The name *cobalamin* has been adopted as appropriate in view of the presence of cobalt and amino groups in the large and complex molecule. Several active forms have been found, and, where necessary to distinguish between them, appropriate prefixes are used, e.g., *cyanocobalamin* for the most studied form, which contains a cyano (—CN) group; *hydroxocobalamin* for the corresponding compound with hydroxyl in place of —CN; and so on. A further distinction is also made: the term vitamin B_{12} is reserved for those compounds which show activity in higher animals and man, while forms which are active for bacteria but not for higher animals are designated as "pseudo B_{12}." Since many of the determinations of vitamin B_{12} in foods have been based on the growth of microorganisms, the existence of this pseudo B_{12} group of compounds introduces an element of uncertainty when the results of such determinations are applied to animal and human nutrition.

It appears that neither animals nor higher plants have the ability to synthesize vitamin B_{12}; but that vitamin B_{12} wherever found in nature owes its origin to the activity of lower forms, chiefly bacteria and actinomycetes. Prominent among these are the intestinal microorganisms, which appear to supply us with a significant (though as yet undetermined) fraction of our need. A source of vitamin B_{12} which may assume considerable practical importance

is seaweed (algae), which may be as rich in this factor as the best known animal products. The origin of this vitamin B_{12} appears to be bacteria associated with the seaweed in growth.

Among the ordinary items of diet, liver is an outstanding source of this factor, muscle meats are much less rich but still important sources, as are milk and other dairy products, and eggs; while products of plant origin are essentially devoid of vitamin B_{12}.

Vitamin B_{12}, like pteroylglutamic acid, appears to be involved in the synthesis of nucleic acids, though not necessarily at the same point. There is also considerable evidence relating vitamin B_{12} to the formation and/or transfer of labile methyl groups, and so with the metabolism of methionine, choline, etc. (see below). A theory relating vitamin B_{12} to transsulfuration (transfer of sulfur groups) has been advanced (Wokes and Picard, 1955). Other suggestions as to the biochemical function of vitamin B_{12} are reviewed by Briggs and Daft (1955).

Vitamin B_{12} is clearly required for normal metabolism in many species, including man. However, partly because intestinal microorganisms appear to synthesize appreciable amounts of it, partly also because the young of well nourished mothers may acquire significant body stores, the requirement becomes more quickly and strikingly apparent if the synthetic activities of the intestinal bacteria are checked, as by the use of certain "sulfa" drugs; or if a metabolic strain, so to speak, is imposed on the body. Examples of such "metabolic strains" were the feeding of diets of very high protein content by the U.S. Department of Agriculture investigators; and the experimental production of socalled "thyroid toxicity" by feeding thyroid or iodinated casein. The detrimental effects on growth of both of these types of treatment are counteracted by liberal dietary vitamin B_{12}. In experimental animals, induced vitamin B_{12}-deficiency has been reported to delay the attainment of maturity in females, to cause testicular degeneration in males, and, during pregnancy, to predispose to congenital abnormalities in the offspring.

We have seen in Chapter 9 that pernicious anemia represents a conditioned deficiency of vitamin B_{12}, brought about by the failure to absorb efficiently the amounts present in the food or formed by the intestinal flora. Whether purely dietary deficiency of vitamin B_{12} is met with in human beings, has been debated. Some

workers have believed that vitamin B_{12} stimulates growth in children who have been on substandard diets: while others report negative findings. Similarly, vitamin B_{12} has been reported beneficial in a vast number of clinical conditions, but seldom under sufficiently controlled conditions to be convincing.

Since, as we have seen, ordinary foods of vegetable origin are practically devoid of this factor, studies on pure vegetarians or vegans, who eat no foods of animal origin—even milk or eggs—should throw some light on the problem of human dietary needs. Hardinge and Stare (1954) noted no symptoms attributable to vitamin B_{12}-deficiency in a group of pure vegetarians, most of whom were adults. On the other hand, Wokes, *et al.* (1955) observed a group of British vegans including children, most of whom had been on the restricted diet for five or six years, who showed low blood levels of vitamin B_{12} and a significant incidence of symptoms which were alleviated by administering vitamin B_{12}. They write:

> The commonest and earliest symptoms have been in the mouth: sore tongues were especially common. These *oral symptoms* generally cleared up after a month or two. *Paresthesia* was another fairly common symptom which developed more slowly and persisted rather longer. *Amenorrhea* and menstrual disturbances were encountered in 8 out of 22 women aged 15 to 45 . . . *Nervous symptoms* were common among the vegans . . . About 20 per cent of the subjects complained of pains in the back and spine. Some of these had stiff "poker" backs, so characteristic that they were termed "vegan" backs.

Similar symptoms were noted in a group of Dutch vegans (see *Nutrition Reviews* **14**, 73–74, 1956), though the incidence was less, perhaps because they had been a shorter time on the restricted diet.

Such studies would seem to indicate that man cannot under all circumstances rely upon his intestinal microorganisms to supply him with all the vitamin B_{12} that he needs.

However, it would be premature to attempt at this time to estimate the total human requirement of this factor and the fraction of this which the intestinal microorganisms will normally supply. Similarly, our knowledge of the true vitamin B_{12} value of foods (i.e., their effectiveness for higher animals and man) is incomplete. But research into these problems is currently active.

Pantothenic Acid

In 1933 this name was given by R. J. Williams to a substance he had discovered to be (as the name was coined to convey) of extraordinarily wide distribution among organisms. It was later shown to be the active factor which had been sought in research on "bios" of yeast, "antidermatitis" (filtrate) factor for chicks, a liver filtrate factor for rats, and a growth factor for lactic acid bacteria.

Pantothenic acid is one component of coenzyme A[1] which occupies a central position in many metabolic processes involving the introduction or splitting off of acetyl and related two-carbon groups. These processes include the synthesis and degradation of fatty acids, sterols, and steroid hormones; the entry of carbohydrate, fat, and the derivatives of certain amino acids into the metabolic pathway known as the *citric acid cycle;* and many others.

An interesting relationship appears to exist between methionine and pantothenic acid. In several aspects of its functioning, smaller amounts of pantothenic acid are required when liberal amounts of methionine are present. Conversely, with liberal amounts of pantothenic acid in the diet, a maximum response to methionine occurs at lower levels (*Review*, 1956*a*; Dinning, *et al.*, 1955).

The symptoms of pantothenic acid-deficiency in animals are many and varied, and, in addition to growth failure, may include in one species or another: dermatitis; nerve involvement, as indicated by incoordination, abnormal gait, even paralysis or convulsions; loss of pigment in feathers of chicks, graying of hair in black rats; and inflammation of stomach and intestines.

The adrenal gland is conspicuously involved in rats. In this species also, a decrease in *normal* immunity (*Review*, 1956*c*) and a reduction in *antibody response* (Axelrod, 1952) have been reported in pantothenic acid deficiency.

It is uncertain whether the diets of human beings are ever sufficiently low in pantothenic acid to produce a deficiency disease; although it was reported that Japanese prisoners of war suffering from the "burning foot syndrome" obtained relief with pantothenic acid. As in the case of pyridoxine, it has been possible to precipi-

[1] The other components are adenine, ribose, phosphoric acid, and an organic sulfur moiety, beta-mercaptoethylamine.

tate deficiency symptoms in human subjects by feeding a metabolic antagonist, in this case omega-methylpantothenic acid (Bean, *et. al.*, 1955; Thornton, *et al.*, 1955; *Review* 1956*b*). Among the symptoms noted were numbness and tingling of the hands and feet, suggestive of the "burning foot syndrome." In addition to this effect on the peripheral nerves, the subjects gave indications of adrenal insufficiency, showed decrease of gastric secretion, had almost continual upper respiratory infections, and suffered from "easy fatigability and somnolence (which) progressed to a quarrelsome and sometimes irascible state." So far observations on induced pantothenic acid-deficiency have been too few and are too new to justify fuller discussion here.

On the basis of studies on dogs, Elvehjem (1950) estimates that "the human requirement cannot be above 5 milligrams a day" which is about the average urinary excretion (Krehl, 1953); while Schmidt found that average (Danish) diets supplied 10 to 20 milligrams of pantothenic acid per day, or about 5 milligrams per 1000 Calories (Krehl, 1953).

Biotin

A sulfur-containing compound called *biotin* was recognized in 1941 as still another member of the "B-vitamin group." Its existence as a factor in mammalian nutrition was discovered through studies on "egg white injury," a curious disease developing in experimental animals fed large quantities of raw egg white. Supplying extra-generous amounts of "B-vitamins" (or of concentrates of biotin) prevents or cures this injurious action of egg white. An explanation of this was found in the presence in egg white of a protein called *avidin* (avidalbumin, antibiotin) which combines with biotin in a firm linkage from which the body cannot detach this vitamin essential to its normal functioning. In later studies, biotin deficiency was produced instead by feeding "sulfa" drugs which prevented intestinal synthesis of biotin.

Attempts to produce biotin-deficiency by feeding egg white to human subjects have been reported as successful by Sydenstricker, *et al.*, but unsuccessful by others. Whether biotin may become a factor of practical importance in human beings given a long course of "sulfa" drug treatment, is also not yet clear.

It has been suggested that biotin is involved in reactions of "carbon dioxide fixation" by which carbon dioxide is incorporated into other compounds, and in the reverse, decarboxylation processes.

Choline ("Labile Methyl")

Choline (chemically, a methylated nitrogenous base) has long been known as a component of the phospholipids, lecithin and sphingomyelin, which are essential structural elements of the body and also importantly concerned in the metabolism of fats. Another compound, acetyl choline, is responsible for the conduction of impulses along the vagus nerve. Choline is thus of unquestionable significance in the body's functioning, yet only fairly recently has it been investigated by nutritionists as a possible limiting factor in certain diets. This is partially because choline differs from our usual concept of a vitamin in that the body appears able to form it if given extra-liberal amounts of such other normal dietary constituents as the amino acid methionine, from which may be transferred the methyl groupings required to build choline.

The process of transfer of a methyl grouping from one compound to another is known as transmethylation, and a methyl grouping which can be so transferred is known as a "labile methyl." The principal forms of "labile methyl" in a normal diet appear to be choline, methionine, and betaine; choline generally being the most important. The body uses "labile methyl" from whatever source interchangeably in such ways as the formation of creatine and the methylation of nicotinic acid prior to elimination by the kidneys. But, in addition, the body has a separate, specific need for choline as an intact chemical entity. Whether methionine, for instance, can fully replace choline in the diet depends upon whether there is available from the body's store of metabolic blocks the residue which can accept "labile methyl" and become choline. In some species of experimental animals and apparently in man, this substance is available. On the other hand, the compound (homocysteine) which, with "labile methyl," yields methionine, is not normally available from other sources, hence choline cannot fully replace dietary methionine, though it can effectively "spare" it by assuming the "labile methyl" aspects of its functioning.

In the sense that the body can apparently form choline if pro-

vided with generous amounts of "labile methyl," it would be somewhat more precise to speak of "labile methyl" rather than choline as the dietary essential. And, *to a limited extent*, even "labile methyl" can be formed by body tissues (apparently from glycine, serine, formate, and/or other normal metabolites); vitamin B_{12} and folic acid seeming to have some relation to this process. These newer findings afford a partial explanation of some of the complex interrelationships which have been found experimentally to exist between proteins (and especially certain amino acids), choline, vitamin B_{12}, and the folic acid group; but should not obscure the fact that choline itself may indeed be the limiting factor in some practical dietaries.

When insufficient choline is available from dietary or metabolic sources, growth of experimental animals is retarded and tissue damage may occur, including hemorrhagic changes in the kidney, and abnormal accumulation of fat in the heart, blood vessels, and liver ("fatty liver"). In kwashiorkor, a disease widely prevalent in underprivileged lands and associated with protein malnutrition (perhaps especially with a shortage of methionine), liver degeneration occurs which is somewhat similar to that just mentioned in experimental animals. The problem of the relation of "labile methyl" to this and other liver diseases seen in the clinics is a challenging one.

EXERCISES

1. Write your own supplement to bring the foregoing chapter up to the date of your study of it.
2. Look up the present status of some of the factors not considered in this text, such as: para-aminobenzoic acid, inositol, alpha-lipoic acid, vitamin P.
3. Write a summary of the present knowledge on the synthesis of vitamins by intestinal microorganisms.
4. Look up vitamin antagonists and their uses in nutrition research and chemotherapy.

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15

VITAMIN A AND ITS PRECURSORS

General Relationships

Vitamin A itself is a colorless, fat-soluble substance found notably in milk, egg, and liver fats, and known to be essential both to the growth process and to the maintenance of normal conditions in the body at all ages. It has not been found in plants; but among the natural orange-yellow coloring matters of green and yellow vegetables there are *precursors* of vitamin A, i.e., substances which give rise to vitamin A in the animal body. These are named alpha-, beta-, and gamma-carotene, and cryptoxanthin.

Structural formulas for vitamin A and for two of these precursors may be found, if desired, on page 463 of the Eighth Edition of Sherman's *Chemistry of Food and Nutrition;* but for our present purpose it will suffice to remember simply the existence of the vitamin and its precursors as a group. For convenience the precursors are often referred to as "the carotenes," or even simply as "carotene."

While there are methods of making *in vitro* determinations of vitamin A and of "carotene" which serve certain purposes, the general basis of comparison between foods of all kinds, or of summing up the contributions of foods of different kinds toward meeting the body's nutritional need, is in terms of *vitamin A values* determined by feeding experiments in which the body of the test animal converts the precursors into the vitamin.

It has been reported that vitamin A occurs in two forms, vitamins A_1 and A_2, the former predominating in the liver oils of salt-water, and the latter of fresh-water fish; but they seem to be very closely related and of essentially the same nutritional character and potency, so we treat the two as one in everyday discussions of food and nutrition.

It appears that the absorption both of vitamin A itself and of its precursors is favored by simultaneous absorption of fat, in which, as we have seen, these factors are soluble. Disease conditions which prevent normal fat absorption may also affect the utilization of vitamin A and its precursors. The taking of mineral oil, which, like fats, dissolves vitamin A and its precursors, interferes significantly with their absorption.

Carotenes as such do not normally accumulate in the body but are changed in the intestinal wall into vitamin A, which is then largely stored in the liver.

Fig. 21. Photographs of twin brothers, showing effects of different amounts of vitamin A in the food. (See text.) (Courtesy of The Forsyth Foundation.)

Vitamin A in Growth and Development

A good first impression of the significance of the level of intake of vitamin A to growth and development is afforded by the quantitatively parallel photographs of twin brothers shown in Fig. 21. At four weeks of age, which we take as representing the end of infancy in the rat, they were of the same size and indistinguishable in their appearance, both being smooth-coated, bright-eyed, alert, and of normal development for their age. From that time they were fed the same diet except that one received butter and the other

did not, though the latter always had as much as he wished to eat of a mixture of vitamin A deficient foods which were all perfectly good of their kinds. At the time these rats were photographed they had reached an age corresponding to about seven years in a boy. The one which had plenty of vitamin A had continued to make a normal growth and development, while the one whose food had been otherwise adequate but very poor in vitamin A was stunted in growth and muscular development, dim-eyed, and sadly lacking

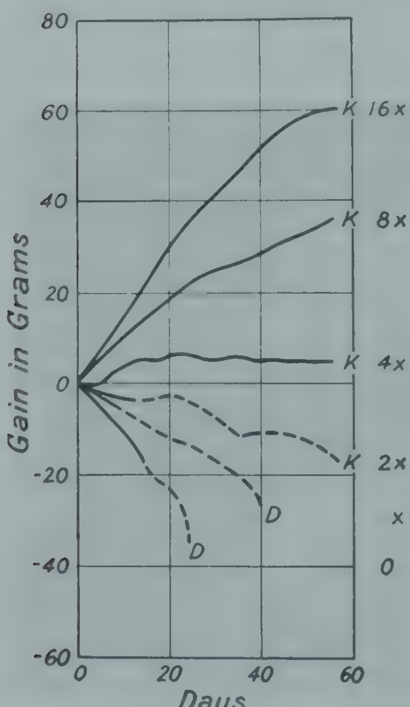

Fig. 22. Effects of graded amounts of added vitamin A on growth in animals maintained on a basal diet lacking vitamin A but good in all other respects.

in alertness. Here the shortage of vitamin A had been so severe as to show its effects upon health as well as growth.

In quantitatively controlled experiments with graded allowances of vitamin A[1] in an otherwise good diet, as in the experiments of Batchelder, the average growth data of which are summarized in Fig. 22, it may be clearly shown that even when there is no such severe shortage as to have any immediately visible effect upon health, the growth may still be limited by the level of vitamin A value of the dietary. In these experiments of Batchelder, for example, the rats receiving the 8x and 16x levels of vitamin A did not

[1] Indicated by multiples of x at the right-hand margin of Fig. 22, in which D = died; K = killed.

show any differences in ostensible health though the ones receiving the more liberal allowance of vitamin A were making better growth.

Such growth experiments provide one means of measuring the vitamin A value of foods.

Demonstration and measurement of vitamin A values. A litter of rats from three to four weeks old, and as uniform as possible in size and apparent health and vigor, affords a good starting point for the demonstration of the influence of differences in vitamin A intake, and of the principle of the feeding method for the measurement of vitamin A values.

When such rats are fed a diet well adapted to their needs in all other respects but devoid of vitamin A value, growth continues for a longer or shorter time according to the body-store of vitamin A possessed by the animal at the beginning of the experiment, which in turn depends chiefly upon the vitamin A value of the previous dietary of the rat, and of its mother. For the purpose of the present experiment it is expedient *not* to use animals from a family whose food supply is liberally fortified with vitamin A; for in such case their body stores may last them so long as to inconvenience the experimenter by the length of time before the appearance of the effect of the experimental diet. The time thus required to use up the surplus previously stored in the body is called the *depletion period*.

When the body is sufficiently depleted of its surplus vitamin A, growth ceases and (with animals as young as here described) usually a loss of weight begins within the next few days, and at about the same time careful examination may begin to reveal incipient abnormalities, or diminutions of positive health.

Animals thus continued upon the vitamin A-free diet (the basal experimental diet alone) *beyond* the depletion period are sometimes spoken of as *negative controls*. In contrast, the *positive controls* are animals (otherwise strictly parallel, of course) which are continued on the same basal experimental diet as the test animals, but with a supplement of sufficiently high vitamin A value to permit them to make fully normal growth and development. Other animals of the group, separated at the end of the depletion period, may be fed different amounts of some material whose vitamin A value is known or is to be ascertained, and in the latter case the work must be so planned as to provide strictly parallel cases, in sufficient numbers, of animals fed the material under test and of those fed the "reference material" whose vitamin A value is quantitatively known.

As may be seen from Fig. 22 there is (when sufficient numbers of cases at each level are averaged) a fairly regular gradation of the weight curves according to the level of vitamin A fed; but the gain is, of course, not arithmetically proportional. The same data represented by this set of curves may be used to construct a *curve of response* representing the relation between the different levels of feeding and the corresponding gains in weight during a feeding period of any length that the experimenter may desire.

At the upper levels of vitamin A allowance, as for instance at the 8x and 16x levels of the experiments represented by Fig. 22, the animals (as in the similar work with thiamine described in Chapter 12) will probably, at this early stage, appear equally healthy, with the difference in rate of growth and development as the only apparent result of the difference in vitamin A intake. At the other extreme, the negative controls sooner or later show evident illness with loss of weight and strength and development of one or more of the lesions described in subsequent paragraphs as results of vitamin A deficiency.

Nutritional Effects of the Level of Vitamin A Value of the Food Consumed

One chief function of vitamin A in the body is the maintenance of a normal condition of the epithelial tissues of the body. Much as we saw that many of the effects of a deficiency of vitamin C could be related to abnormal function with respect to the intercellular cement substance, we now find that many facets of the picture in vitamin A deficiency are associated with abnormalities in the epithelial tissues.

The Skeleton, the Muscles, and the Skin. A higher level of vitamin A intake during growth induces the probability that at a given age the body will not only be heavier but also more long and lithe, with better-formed bones and teeth, better muscular development and muscle tone, and a superior condition of skin "like the sleekness of a well-conditioned farm animal."

Even after such losses of the living impression as are involved in its transfer, first to the photographic plate, then to the engraver's block, and then to paper, the reader may still be able to see something of this difference between the twin brothers shown in Fig. 21.

As Wolbach pointed out, severe vitamin A deficiency in young animals brings about a cessation of normal bone growth before

growth of the soft tissues ceases. One effect is overcrowding and pressure on the central nervous system, which sometimes results in paralysis. The reverse effect, overstimulation of bone growth, is a prominent feature of *hypervitaminosis A*, which has occasionally resulted from repeated large overdoses of vitamin A preparations through accident or misunderstanding.

McCollum considers a certain dryness of the skin as one of the earliest indications of a shortage of vitamin A. The observations of MacKay upon babies of the London poor indicated that a mild shortage of vitamin A was retarding their growth and making their skin less wholesome and resistant. This condition she was able to cure, by enriching the diet in vitamin A, before the development of any of the more drastic symptoms.

The Eye: Xerophthalmia and Nightblindness. In an experiment with laboratory animals such as was outlined above, xerophthalmia is usually the first noticeable characteristic symptom of the vitamin A deficiency. In work with cooperative human subjects a slight but detectable degree of nightblindness (difficulty of adaptation of vision to diminished light) is now generally regarded as a delicate indication of an incipient deficiency of vitamin A.

The former is a special case of the general tendency of shortage of vitamin A to affect the mucous membranes, while the latter has to do with an independent function of vitamin A in the visual process.

Xerophthalmia (keratomalacia, conjunctivitis) is a condition of dry inflammation of the eye-lids and the outer surface of the eye which, soon after the discovery of vitamin A, was observed by Osborne and Mendel to be a frequent consequence of a shortage of this factor. In the early stages there is cornification of the sclera and cornea which may develop into "Bitot spots" (tiny lumps or puckers with decreased translucency). Follicular conjunctivitis and granular lids may also develop. Later, under continued shortage of vitamin A, the cells of the lachrymal gland cease to pour out their normal secretion. The external eye thus becomes dry, bacteria multiply and are not washed away, the eyelids become congested and sometimes so swollen, sticky, and scabby as to close the eye. In extreme cases the cornea may be attacked and permanent blindness may result. Mori observed such an eye disease among children of the Japanese poor and found that it could be cured (if not

too far advanced) by chicken livers, fish livers, or codliver oil. Much blindness in the Orient today is said to have been caused by vitamin A deficiency. Excessive exportation of butter from Denmark during 1914–1918 caused a shortage of vitamin A in the food of the poorer people with resulting high prevalence of xerophthalmia in Danish children as reported by Bloch and by Blegvad.

Kruse (1941) has especially studied slight degrees of xerosis which he believes precede gross xerophthalmia and constitute a delicate test for early mild stages of vitamin A deficiency, which he thus finds to be much more prevalent than hitherto supposed. For example, the Milbank Memorial Fund studies of *dietaries* of New York City high school students indicated that vitamin A was *their* most frequent deficiency; and correspondingly "changes in the conjunctiva associated with avitaminosis A were present in 88 per cent of 278 boys and 85 per cent of 216 girls" (Wiehl, 1942).

Nightblindness (*hemeralopia*), diminished ability to see clearly in a dim light, especially when the eye has recently been exposed to a bright one, is a defect of vision which has now been extensively investigated with results which show that vitamin A has a very fundamental role in the visual process.

The present state of knowledge with respect to the biochemistry of vision has been summarized by Wald (1953). To present in fully explicit fashion the chemical and physical mechanisms involved would lead beyond the scope of this book. As bearing on the relation of nutrition to vision, it is of interest to point out that both the *rods* of the retina, which are particularly concerned with vision in dim light (*scotopic* vision), and the *cones* of the retina, which have to do with color discrimination and with vision in bright light (*photopic* vision), contain pigments comprising vitamin A and a characteristic visual protein. In the case of the rods, the pigment, *rhodopsin* (originally called visual purple), consists of vitamin A[2] and a protein known as *scotopsin*. In the case of the cones, the pigment, *iodopsin*, also contains vitamin A but the protein is different (and has been called *photopsin*). In essence what is supposed to occur when light strikes the rods is a rapid breakdown of rhodopsin to vitamin A aldehyde (*retinene*) and protein, which initiates the nerve impulse. In the regeneration of rhodopsin some of the constituent vitamin A is recovered by the reduction of retinene (a process involving dehydrogenase systems and Coenzyme I) but apparently some vitamin A

[2] In the case of certain fresh water fish, the pigment is known as *porphyropsin* and contains vitamin A_2.

must be supplied anew from the blood. Unless vitamin A or its aldehyde is supplied by the blood in adequate amounts, the formation of rhodopsin (and hence the recovery of the ability to see in dim light) is impaired, giving rise to nightblindness. According to Wald (1953), experiments on human vitamin A deficiency have shown that cone vision deteriorates along with rod vision, and both recover together on administration of vitamin A or carotene.

The Respiratory System. As Bessey and Wolbach (1938) explained, the characteristic histological changes of vitamin A deficiency, found in many epithelial structures, consist of: (1) atrophy of some of the normal cuboidal surface cells of epithelium, (2) reparative proliferation of basal cells, and (3) differentiation of this new material into a stratified keratinizing epithelium. Many of the visible pathological features of the deficiency in man, and animals, they explain, are the results of accumulation of keratinized epithelial cells in glands and their ducts and in other organs. This is true of xerophthalmia, which has already been considered.

The distribution of such keratinizing metaplasia and the sequence of its development as between, for instance, the eyes, the respiratory system, and the genito-urinary tract, tends to vary both with species and with the age at which the vitamin A deficiency is encountered. Bessey and Wolbach emphasized the danger of vitamin A deficiency to the respiratory tract. They found that in the human infant the commonest and earliest appearance of epithelial metaplasia is in the trachea and the bronchi. Blegvad, following the histories of Danish infants who showed eye troubles due to vitamin A deficiency during 1914–1918, found that a large proportion of them ultimately died of respiratory disease.

The Genito-Urinary System. Osborne and Mendel found that phosphatic calculi ("bladder stones") developed in the urinary tract of a large proportion of their vitamin A deficient rats. Apparently the precipitation of phosphate may be induced by a local infection which in turn is attributed to an abnormality of the epithelium resulting from the vitamin A deficiency.

Atrophy of the testes and disturbances of the female reproductive system due to the keratinizing metaplasia already discussed have been observed in vitamin A deficient human beings as well as in experimental animals.

For the support of successful reproduction and lactation the diet

must furnish more vitamin A than is needed for even the most rapid growth. For instance, in the rat families studied by Sherman and MacLeod (1925) a diet of relatively low vitamin A value supported growth surprisingly well for some time but failed utterly when put to the further and more rigorous test of its adequacy to the successful launching of a second generation. On this low vitamin A diet the females (although not showing any outward signs of vitamin A deficiency) either bore no young or failed to rear any of the few that were born, while in parallel families of the same hereditary background and with diets entirely similar except that they contained more milk-fat, reproduction and rearing of young proceeded normally.

Later studies (summarized by Hogan, 1953) have emphasized that such young as the vitamin A deficient mothers are able to produce tend to be defective or malformed at birth.

Relation to Infections. As has been mentioned in connection with several parts of the body, so it may be said of the body as a whole that the changes in the epithelial tissues which result from vitamin A shortage are such as to weaken what the *Journal of the American Medical Association* has called "the body's first line of defense" and so increase the frequency or the severity or the duration of localized infections, occurring in or gaining access through the damaged epithelial tissues. Whether there is also a generalized relation of vitamin A to infections, is still under investigation (see *Review* 1956*a*, *Review* 1956*b*).

Storage of Vitamin A in the Body

Vitamin A can be stored in the body to a large extent, and with far-reaching results.

As Bessey and Wolbach summarize it, some animals have a remarkable capacity for such storage, "illustrated by the fact that a rat may in a few days store enough vitamin A to supply its nutritional needs for several months." Usually over nine-tenths of the body's store of vitamin A is found in the liver, the amount thus stored depending upon the nutritional background, how large a surplus the food has supplied and for how long. Lung and kidney tissues have much less than liver, but still measurable amounts; and it has been found that the level of vitamin A feeding influences

the amount of vitamin A in the lung. Muscle contains so little as to be practically at the lower limit of measurability even when the level of nutritional intake of vitamin A is liberal. Adipose tissue may, however, contain a significant amount.

Agreeing fully with Bessey and Wolbach that the rat is able to store vitamin A in the body in sufficient amounts to meet nutritional needs for a relatively long time, we would also emphasize the fact that the limit of the body's capacity for storage of vitamin A is not quickly reached. Thus in one series of experiments it was found that whether the opportunity for bodily storage was afforded

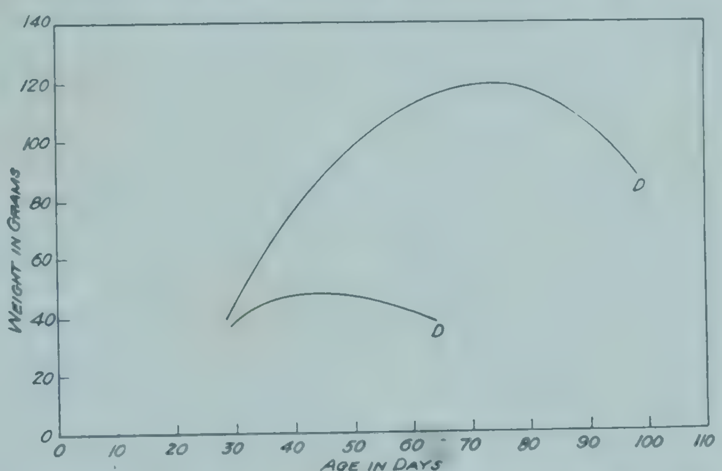

Fig. 23. Curves illustrating the effects of differing initial bodily stores of vitamin A in animals transferred to vitamin-A-free diet.

by parallel additions of 1, 2, or 4 per cent of codliver oil to an already-adequate diet, or by feeding the diet fortified with 4 per cent of codliver oil for different lengths of time, in either case the body first stored rapidly from the surplus fed, but thereafter continued to add slowly to its store for as long a time as the experimental feeding was continued, and increasingly with the level fed up to the highest fortification tried. More recent work shows even more strikingly the ability of the body to continue storing vitamin A throughout long-term experiments (Sherman and Trupp, 1949).

By the end of infancy, differently fed individuals of the same species and racial stock or strain may have quite different bodily reserves of vitamin A. Thus, in the experiments summarized in Fig. 23, young rats of the same colony but whose families' dietaries consisted of (1) one-sixth dried whole milk with five-sixths ground

whole wheat (Diet 16), and (2) two-thirds dried whole milk with one-third ground whole wheat (Diet 70), respectively, were transferred at the age of 28 days to the same vitamin-A-free diet. Those from Diet 16 with its approximately minimal-adequate vitamin A content had only sufficient body store to grow about 10 grams and to survive an average of 34 days, while those from Diet 70, which contains about four-fold more vitamin A than does Diet 16, had enough body store at the same age, to grow about 70 grams and survive an average of 65 days on the same vitamin-A-free diet. The difference in vitamin-A values between these two family dietaries is no greater than the differences which currently exist between many of those of American families (and often even between families of the same locality and same economic level) depending upon their different choices of food.

With older animals there is necessarily much less opportunity for growth to enter into the comparisons; but comparisons of rats taken at different ages from the same home dietary, which in this case had about twice the minimal-adequate level of vitamin A, showed that the length of time they could survive upon a vitamin-A-free diet continued to increase with their age up to adulthood. While this mode of investigation is in itself perhaps less clear-cut and conclusive than the one above described, it is significant as evidence of yet another kind that the body continues for a relatively long time to add to its reserves of vitamin A if the food contains a surplus above immediate nutritional need.

Lack of complete realization of the full extent and significance of this phenomenon of widely differing bodily storage has undoubtedly sometimes been a cause of misinterpretation of human experience and of undue skepticism regarding the importance of the vitamin A level in the human food supply. There is evidence suggesting that the reserves of vitamin A in the normal human being are lowest at birth (even with a favorable maternal diet), increasing with advancing age on ordinary diets. Thus (*Review*, 1943) it has been estimated that very young infants have a reserve of vitamin A sufficient to carry them three to four months, while children over a year old have stores to meet their needs for perhaps twice as long; whereas it has been calculated that it would take from one to two years to exhaust completely the liver stores of a well nourished human adult.

Considering the evidence now available on the quantitative role which body storage can play in the growth and health of the rat, and taking account of the relative lengths of life in the two species, it appears that human subjects would have to be kept for years under strict observation in order fully to control the differing influence from their different nutritional backgrounds.

Full-Life and Successive-Generation Experiments

The investigations mentioned earlier were extended by Batchelder in a series of full-life and successive-generation experiments with rat families fed diets of systematically graded vitamin A content. Those at the minimal-adequate level of vitamin A intake grew to normal size (though in the lower ranges of the normal zone), were successful in bearing and rearing young, lived to an age within the normal range of longevity, without showing any specific sign of vitamin A deficiency, and left vigorous offspring. On a level of vitamin A intake twice as high, the performances in all these respects were again within the normal range, but the average record was slightly higher with respect to every one of the criteria just mentioned. Parallel animals on a level of vitamin A intake four-fold higher than that of minimal adequacy again made slightly better average records than those on the two-fold level. At a level eight-fold that of the minimal-adequate vitamin A requirement, the original animals showed no measurably different responses from those on the four-fold level; but the higher of these two levels seemed to confer a still further benefit upon the offspring. (It will be remembered from Chapter 13 that in the case of riboflavin—as here of vitamin A—when liberality of intake has been carried to the "plateau level" of adult response, further increments may still show further benefits to the offspring.)

More recently the Columbia laboratory with the aid of grants from The Nutrition Foundation resumed and extended its experimental studies of the effects of different levels of vitamin A intake with results which permit of more positive and quantitative conclusions, especially as regards the relation of the vitamin A value of the diet to the length of life. Starting with a diet which previous and parallel work has shown adequate to the degree that rat families are still thriving upon it in the 82nd generation, it was found

that doubling the vitamin A value of the diet increased the average length of these already normal lives. And moreover, on again doubling the vitamin A value of the diet there followed further improvements of life history to the extent that in terms of the original (adequate but suboptimal) level, quadrupling the original intake increased the already normal length of life: of males, 10.4 per cent; and of females, 12.1 per cent. Moreover, in these same experiments, the socalled "useful life" (that part of the life cycle which lies between the attainment of maturity and the onset of senility) was increased in greater ratio than the life span itself.

Whatever form the final explanation may take, the fact is shown by experiment for vitamin A (as it has been also for vitamin C and for calcium) that the difference between minimal adequate and the optimal intake is much wider than had been supposed, or than is probable for many other factors in nutrition.

This means that the science of nutrition has greater constructive potentialities than hitherto supposed. Also, it meanwhile complicates the problem of quantitative standards of "requirement."

Human Requirements for Vitamin A

In view of the facts mentioned in the preceding paragraphs, the question, how much vitamin A value is required in human nutrition?, logically raises a further question. Required for what: for the maintenance of passable health with prevention of frank symptoms of deficiency, or for the support of the highest degree of nutritional wellbeing and positive health that each individual is potentially able to attain?

This distinction being relatively new, there are still some people who regard it as more or less speculative. On the other hand, the reality of the difference is recognized as highly significant by those who sufficiently study the quantitative experimental evidence. Thus it is gradually coming to be considered that human requirement should mean not only what is needed for the prevention of specific deficiency symptoms, but further what is needed to permit a human population to realize fully the potentialities of its hereditary birthright.

When an attempt is made to express this need in the more general terms of vitamin A *value*, to take account of the fact that caro-

tenes as well as vitamin A itself contribute toward meeting it, further difficulties present themselves for the reason that man may not have the same ability to convert the precursors into vitamin A as have the experimental animals on which the biological equivalency of the various forms was established. Thus, by official definition, *one International Unit of vitamin A activity is that possessed by 0.3 microgram of pure vitamin A or by 0.6 microgram of beta-carotene.* And, on the basis of tests with experimental animals it is usually considered that the other carotenoid precursors have only half the biological potency of the same weight of beta-carotene.

But there are indications that in human nutrition one International Unit as vitamin A is somewhat more effective than one International Unit as carotene. Thus, in a wartime effort to determine the minimum human adult need for vitamin A, the Medical Research Council of Great Britain estimated that 2500 International Units in the form of 750 micrograms of vitamin A itself would suffice; while of beta-carotene in oil 3000 International Units (1800 micrograms) were suggested to meet the same need; and it was stated that 7500 International Units would probably be required if green vegetables were to provide the sole source. Somewhat similarly, Booher, Callison, and Hewston (1939) found the minimum requirements for the maintenance of the normal efficiency of the eye in the dark-adaptation test in five "ostensibly healthy" adults to vary from 1750 to 3850 International Units per day when taken in the form of vitamin A itself, or 3010 to 7210 International Units per day when taken in the form of carotene dissolved in cottonseed oil. And, in the text accompanying the National Research Council's *Recommended Dietary Allowances*, it is considered that twice as many International Units are required by man when taken as beta-carotene as when taken as preformed vitamin A.

When experiments show such a wide apparent range in even the minimum requirement, both as between individuals and according to the form in which the vitamin A value is supplied, and it is still a matter of varying judgment among nutritionists how the optimal allowance shall be related to the minimum (or "rock bottom requirement"), it is obvious that attempts to state human requirements in precise quantitative form must, for the present, be largely matters of judgment. The present writers favor the liberal

allowances recommended by the National Research Council in 1953.

The Recommended Dietary Allowances of the National Research Council's Food and Nutrition Board provide:

5,000 International Units for normal human adults, rising to 6,000 for women in the last trimester of pregnancy and 8,000 during lactation;
1,500 such units for children under 1 year of age;
2,000, for children of 1 to 3 years;
2,500, " " " 4 to 6 " ;
3,500, " " " 7 to 9 " ;
4,500, " " " 10 to 12 " ; and
5,000 for young people of 13 to 20.

It is stated that "each allowance has been calculated on the basis of an intake *approximately double that meeting minimal requirements*, and assuming a diet of natural foods contributing two-thirds of the total vitamin A activity as carotene and one-third as the preformed vitamin. The allowance for the reference man, therefore, is 5000 I.U. as provided by 4000 I.U. of carotene and 1000 I.U. of vitamin A. Six thousand I.U. or 3600 micrograms of beta-carotene would meet this allowance totally. If the sole source were preformed vitamin A, 3000 I.U. or 900 micrograms would be needed."

Whether these recommended allowances will seem sound investments will depend largely upon the degree of acceptance: (1) of the methods and criteria of Kruse which tend to show, by direct observations upon the human population, that slight deficiencies are more frequent and actual requirements therefore higher than hitherto supposed; and (2) of the evidence from full-life and successive-generation experiments with laboratory animals indicating that in the case of vitamin A there is a wide zone of beneficial increase between the minimal-adequate and the long-run optimal level of intake.

Vitamin A Values of Foods

One may give much weight to the vitamin A values of foods in the planning of the dietary, or one may leave the responsibility for vitamin A very largely to the regular taking of fish-liver oils, which are enormously potent in this factor. Probably the best plan is to

give considerable weight to vitamin A values in the choice of foods or planning of food budgets, so that in satisfying our hunger we shall have ingested at least a minimal-adequate amount of vitamin A, and then (for "insurance" or "good measure" or for the further promotion of positive health) take fish-liver oil also, at least during the winter months.

TABLE 28. *Vitamin A Values of Certain Foods*

Food	*International Units per 100 Grams*
Foods of Animal Origin	
Muscle meats	trace
Liver (beef)	43,900
Milk (whole)	160
Butter (year-round average)	3,300
Eggs	1,140
Egg white	trace
Egg yolk	3,210
Fruits and Vegetables	
Apples	90
Apricots, fresh	2,790
Asparagus	1,000
Bananas	430
Beans, baked	30
Carrots	12,000
Dandelion greens	13,650
Mustard greens	6,460
Peas, fresh young green	680
Potato	20
Sweetpotato (varying with color)	2,000–7,700
Tomato	1,100
Fish-liver oils	around 200,000

The green leaf vegetables as a group and such yellow vegetables as carrots and the highly colored varieties of sweetpotatoes are rich in carotene and so are of high vitamin A value.

Grasses and other forage plants which (in America and Europe at least) are not classified as human foods, are also of high vitamin A value, and in milch cows and laying hens the human family has very efficient servants for bringing into forms excellently adapted to our use (milk and eggs), the values of more fibrous leaves than

we ourselves would care to eat. The vitamin A of dairy products follows the milk fat in processing, so that butter, ice cream, cream, "store" cheese, cream cheese, and other products which retain the butterfat are good sources, while cottage cheese, and fresh or dried skimmilk, contain but little vitamin A value.

Muscles take up extremely little vitamin A, even when the animal is abundantly supplied; so clear lean muscle meats are always of low vitamin A value. Liver is, weight for weight, usually a very much richer source, but apt to be variable depending upon how the animal has been fed. Adipose tissue probably contains more than clear lean but very much less than liver.

The cereal grains, and therefore their mill products, and bakery products (unless made with milk, butter, fortified margarines, or eggs) contain only insignificant amounts of vitamin A or of any of its precursors. This is also true of sweets and of most commercial fats and fatty oils.

However, most oleomargarine sold today for table use has been fortified by the addition of vitamin A, usually in amounts intended to make it equal in this respect to the year-round average of butter.

So far, it has been possible to speak in general terms which are valid for general types of food. There are, however, other foods which are too variable to be accurately covered by these general statements. Thus not only is the vitamin A value enormously higher in carrots than in turnips; but also in deep-yellow than in pale-fleshed sweetpotatoes, in Hubbard squash than in pale-fleshed summer squash, in loose-leaf than in tightly headed lettuce, in the green growing tip than in the white stalk of asparagus, and so in many other such cases. For example, Kramer, Boehm, and Williams found the green outer leaves of lettuce to have 30 or more times as high vitamin A value as the white inner leaves from the same heads.

It has already been pointed out that the different precursors of vitamin A may have different biological values, relative to vitamin A itself, in man than in the test animals used for vitamin assay. In addition, carotenes from one food source may be utilized more efficiently than those from another, to an extent and for reasons not yet fully understood, while the character of the diet as a whole also affects the utilization of the various substances having vitamin A value.

There is thus a large measure of uncertainty in our present

knowledge of this vitamin factor, not only as to the actual human need for optimum nutrition but also in regard to the effectiveness of various food sources in supplying it. Both the Recommended Allowances and the tables of food values are to be regarded as provisional and tentative and more precise definition of both may be hoped for in the near future. Meanwhile one may well be liberal in planning his vitamin A intake, since dairy products and green vegetables, which are so prominent as sources of this factor, are also of very great nutritional significance for many other reasons as well.

EXERCISES

1. Arrange your "forty foods" in the order of, or in groups according to, their vitamin A values: (*a*) per 100 grams; (*b*) per 100 Calories.

2. Divide a litter of rats between three and four weeks old into two groups as nearly equal as possible in size and in the distribution of the sexes. To one group feed a diet[3] adequate (to the needs of rats) in all respects, and with its vitamin A supplied solely in the form of butter or butterfat. To the other group feed a diet similar except for the substitution of lard or cottonseed oil for the butter or butterfat. Several weeks may elapse before the nutritional effects of this difference in diets begin to appear.

3. If circumstances permit, duplicate the preceding Exercise with a parallel experiment using a litter of rats whose home diet has been distinctly richer or poorer in vitamin A value.

4. Compile recent evidence on the utilization of provitamins A by human subjects.

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16

RICKETS AND THE VITAMINS D

Straight, sturdy bones and sound teeth are among the most readily apparent and appreciated rewards of good nutrition. In an earlier chapter we have discussed the importance of providing liberal amounts of the inorganic elements which give these structures their characteristic strength and rigidity. Here we shall consider the rôle of a group of organic substances known as the vitamins D in assuring efficient utilization of the dietary calcium and phosphorus, in particular with regard to the development of normal bones. The teeth are given special consideration in Chapter 18.

Growth of Normal Bone

A detailed description of the physiological and histological processes of bone development would be inappropriate to this text. However, the relation of nutrition to these structures will become clearer if there is some understanding of the principal factors concerned in the formation of normal bone. Let us therefore consider briefly the sequence of events by which growth of a typical long bone is accomplished.

The main body or *shaft* of a long bone is known as the *diaphysis*. Separated from the shaft in young, growing individuals by a region of cartilage, but later becoming a part of the long bone, is a smaller bone, known as the *epiphysis* or *head*. Growth takes place by the continuous formation of new cartilage cells along the epiphysial margin. Normally, there is simultaneous degeneration of older cartilage cells along the diaphysial border. The cavities so formed are invaded by blood vessels from the marrow of the shaft, carrying inorganic elements which are deposited as relatively insoluble salts (chiefly of calcium and phosphorus) in the *matrix* or intercellular substance of the degenerating cartilage cells, forming what is

known as the *zone of provisional calcification*. Accompanying the blood vessels are cells known as *osteoblasts* (bone-formers) which surround themselves with socalled *osteoid tissue*, into the matrix of which inorganic salts are laid down to form true bone.

All of the factors determining the deposition of bone salt are not understood. It is known that calcification cannot occur unless adequate supplies of calcium and phosphorus are available. But it is also clear that growing bone must have some special property, not shared by body tissues in general, by virtue of which precipitation of "bone salt" from blood of normal calcium and phosphorus content occurs in the bones but not in other tissues of the body.

The Nature of Rickets

Rickets is a condition, developing principally in infants and young children, in which the mineral metabolism is disturbed in such a way that calcification of the growing bones does not take place normally. In the majority of cases the failure of the bones to calcify appears to be due, not to any initial fault of the bone itself, but to some deficiency in the blood: for rachitic bones placed in normal blood serum usually begin at once to calcify; and a subnormal concentration in the blood of either calcium or phosphorus (or both) is generally found associated with rickets. However, Dr. Alfred Hess, one of the foremost authorities on the disease, observed indications that the primary deficit in *certain cases* of rickets concerned a *local* factor affecting the "anchorage" of the available calcium and phosphate in the end of the growing bone.

In rickets, the proliferation of cartilage cells and even of osteoid tissue continues, giving rise to a wide band of epiphysial-diaphysial cartilage. Calcification, however, fails to occur, and consequently no zone of provisional calcification is observed. Since these proliferative tissues do not become properly hardened by the deposition of bone salts, the strain of bearing the body weight causes enlargement of the ends of the bones. This gives rise to the familiar enlarged joints and row of beadlike swellings at the rib junctions commonly called the "rachitic rosary," which are among the prominent clinical signs of rickets. As the disease continues there may be loss of already deposited mineral salts from the shaft, with consequent further weakening of the bones. "Knock-knees" or "bow-legs" com-

monly develop as the result of such weakness, and, for mechanical reasons, are apt to be especially severe in the heavy, otherwise well nourished, infant and in the child who begins to stand at an unusually early age.

Although rickets itself is seldom fatal, it may result in permanent deformities, which, besides their sometimes tragic effects upon the appearance and happiness of the individual, are often responsible for grave physical misfortunes. Thus, malformations of the pelvis as the result of rickets in early life may persist into adulthood and cause injury at the time of childbirth to mother or child or both. In the opinion of Hess, these "constitute the foremost burden of rickets on the community." There are also indications of a heightened susceptibility to respiratory disease in severe rickets.

Discovery of the Antirachitic Factor

It has already been pointed out that the immediate cause of most cases of rickets appears to lie in a subnormal concentration of calcium ions or phosphate ions in the blood. Sometimes this low concentration may be traced to an inadequate mineral content of the diet. But, since mild rickets sometimes develops in infants fed almost exclusively on milk and thus liberally supplied with calcium and phosphorus, it is evident that the explanation of such cases must be sought in some further factor or factors controlling the *utilization* of these elements. This aspect, which has figured prominently in the history of both clinical and experimental rickets, may now be considered.

Many investigators had noticed the prevalence of rickets among children living in dark, crowded quarters, and the greater incidence of the disease in winter than in summer; and as early as 1822 a Polish physician, Jedrzej Sniadecki, clearly stated his belief that the exposure of the body to direct sunlight was of importance in both the prevention and the cure of rickets (or *English disease*, as it was commonly called in that day).[1]

This view of the significance of sunlight did not receive general acceptance until years later. Many careful students of the problem felt rather that other hygienic factors were primarily at fault in the

[1] Mozolowski, W. 1939 Jedrzej Sniadecki (1768–1838) on the cure of rickets. *Nature* **143**, 121.

dark, unsanitary quarters where rickets was so prevalent. In 1890, however, Palm, an English physician who had practiced for some years in Japan, published the results of his correspondence with medical missionaries throughout the world to whom he had addressed queries regarding the occurrence or absence of rickets in their territory, the habits of the people, and the climatic and sanitary conditions. This remarkable survey revealed the complete absence of the disease in certain sections of the world where sunlight was abundant but where food and general hygienic conditions were extremely bad; and led Palm to the conclusion that the main etiological factor in rickets is a lack of sunlight.

About the time of the World War I, pediatricians discovered that, besides direct sunlight, artificial sources of ultraviolet light such as the mercury-vapor quartz lamp were effective for the cure of rickets in infants exposed to them under suitable conditions.

At just about the same time, studies on experimental rickets were lending support to the theory that a dietary factor was involved in the prevention and cure of this disease. Dr. (later Sir) Edward Mellanby observed the development of rachitic symptoms in puppies on a restricted diet, and showed that codliver oil was very effective, whereas lard was entirely ineffective, in preventing these abnormalities of the bones. Various investigators in this country induced rickets in rats by feeding diets of severely imbalanced mineral content, and showed that this experimental disease also could be largely prevented or cured by codliver oil. It was soon made evident that the fat-soluble dietary factor or vitamin here involved was different from that already recognized as related to growth and to the prevention of eye-symptoms; for, as shown by McCollum, even after this latter factor (vitamin A) had been destroyed by bubbling oxygen through hot codliver oil, the oil retained its antirachitic properties. The term "vitamin D" was, therefore, adopted for the antirachitic factor.

The reconciliation of these two seemingly divergent views as to the rickets-preventing agent followed the discovery in 1924, independently by Hess and by Steenbock, that exposure of many food materials to *ultraviolet light* endows them with the nutritional properties attributed to *vitamin D*. To the substance originally present in the food which the ultraviolet rays "activate," the name *provitamin D* was given. Further experimentation showed that it

or a similar substance occurs in the sebaceous secretion of the skin, and that when the skin is exposed to direct sunlight or other source of ultraviolet light this provitamin D, just as that in food materials, is transformed into vitamin D, which is in turn absorbed through the skin and distributed throughout the body, where it functions in exactly the same way as if it had been taken by mouth in fish liver oils or irradiated foods. Thus, the sunlight and the vitamin effects in rickets are but different aspects of the same phenomenon.

The statistics of rickets in Chicago which are cited in Rose's *Feeding the Family*, Fourth Edition (1940, page 170), illustrate the extent to which this branch of the newer knowledge of nutrition has solved its problem, and also give reassurance as to the mildness of most of the rickets recently diagnosed. In the Chicago examinations of pre-school children during the years 1926 to 1932, from 21 to 16 per cent revealed evidence of rickets, but in 1933 only 13.7 per cent of the newly examined children showed signs of rickets, and in 1935 only 7.1 per cent showed any indications and only 0.03 of one per cent showed severe rickets. Thus the incidence of such rickets as is to be regarded as really a disease in the usual sense of the word has been reduced to three cases per ten thousand children.

Park and associates (Follis, *et al.*, 1943) found *histologic* evidence of rickets in almost half of the children 2 to 14 years old whom they examined at autopsy, although only a few would have been judged rachitic by x-ray examination. Since these authors state that: "We doubt if (such) slight degrees of rickets . . . interfere with health and development;" and further, since the possibility remains that the rickets may have developed during the terminal illness, these findings need not be regarded as alarming or as contradictory to the optimistic view just presented. Yet they do, as the authors conclude, "afford reason to prolong administration of vitamin D to the age limit of our study, the fourteenth year, and especially indicate the necessity to suspect, and to take the necessary measures to guard against, rickets in sick children."

In a later report (Follis, *et al.*, 1953) these investigators were impressed by the high incidence of "moderate or severe" rickets in a younger group of children, two months to two years old. Many of these children were found never to have received supplementary vitamin D. That some underprivileged members of our population even today are thus not receiving the benefit of antirachitic treat-

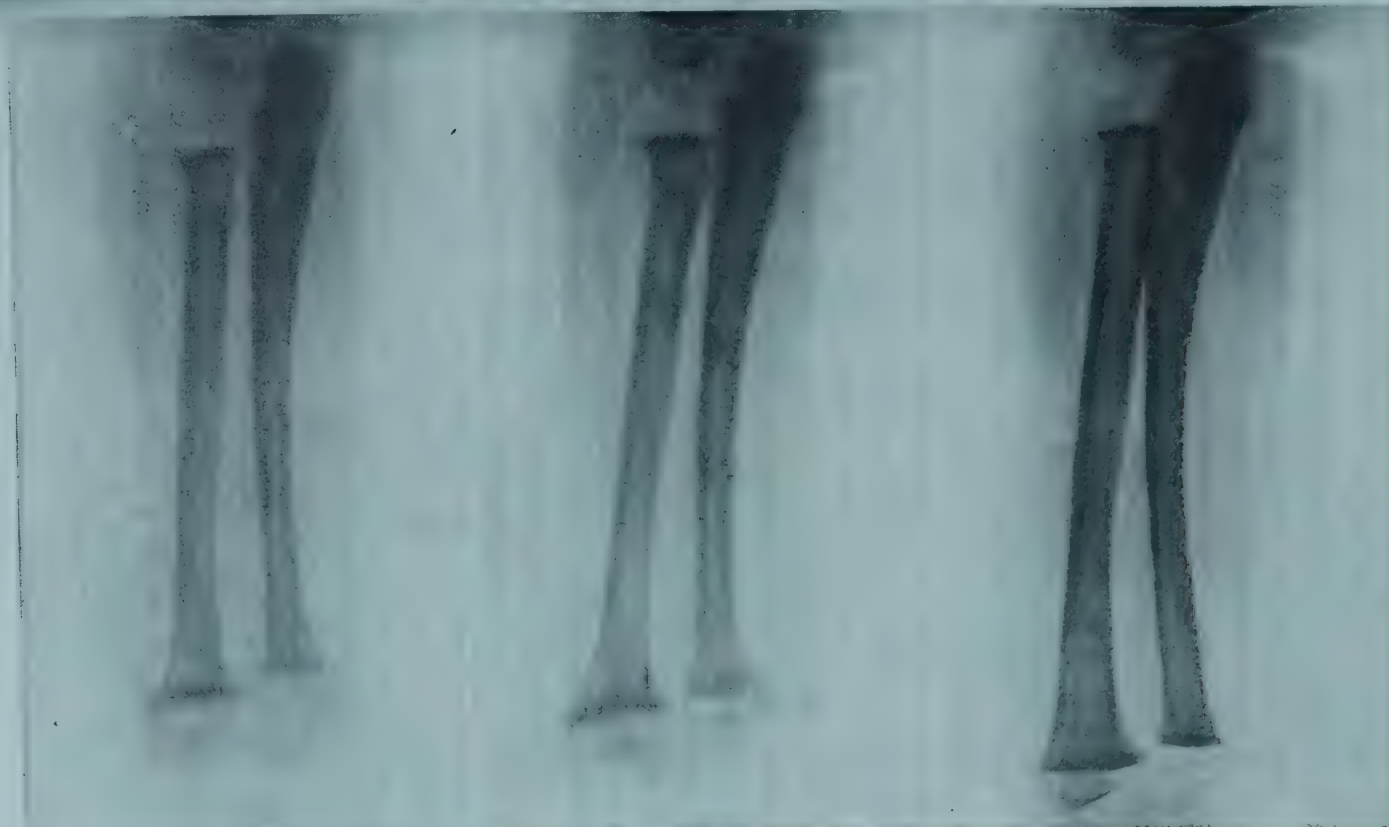

Fig. 24. Three x-ray photographs of the right wrist of the same girl. The first shows active rickets with marked flaring of the end of the long bone and fringing where calcification is retarded. The second shows increased calcification as the result of codliver oil and sunlight. The third shows a normal density of calcification and a smooth end of the long bone when further treatment had completed the healing. (Courtesy of Dr. Martha Eliot.)

ment is one reason that some pediatricians have recommended administration of very large doses of vitamin D twice a year under medical supervision, as noted below.

Figure 24 shows x-ray photographs of the wrist of the same girl: (1) with active rickets of a degree now classified as "severe" (though not of such deforming severity as was common a generation ago); (2) when the rickets was healing; and (3) when it was healed.

Nature and Multiplicity of the Vitamins D

It is now well established that there are several vitamins D, two of which are important.

The provitamins which are converted to vitamins D by the action of ultraviolet light belong to the group of substances known as *sterols*, of which brief mention was made in Chapter 2. Neither of the sterols occurring naturally in greatest abundance, *cholesterol*, found in animal fats, and *sitosterol*, in higher plants, is of significance as a precursor of vitamin D. But present in small amounts along with these are other, more highly reactive, sterols, notably *7-dehydrocholesterol*[2] in animal fats and *ergosterol* in both higher and lower plants, which are changed on exposure to light of suitable wave-length into potent antirachitic substances, designated, respectively, as *vitamin* D_3 and *vitamin* D_2 (or *calciferol*). These two products appear to be the forms of vitamin D of greatest importance in antirachitic foods and medicines, but a dozen or so chemical substances have been shown to have the calcification-promoting properties ascribed to "vitamin D."

Vitamin D_3 (activated 7-dehydrocholesterol) is the most prominent form of antirachitic vitamin in fish liver oils, irradiated milk, and irradiated animal products generally, and is believed to be the D-vitamin developed in the skin on exposure to ultraviolet light; whereas vitamin D_2 (activated ergosterol, calciferol) is the form widely used medicinally in preparations such as "viosterol," and is present also in irradiated yeast, in the milk of cows fed irradiated yeast (sometimes called "metabolized" vitamin D milk to distin-

[2] For the sake of explicit identification of important substances a few somewhat technical chemical names are here given in the text. They need not be memorized. They may be found useful for reference in further reading.

guish it from milks fortified with this factor in other ways), and in minor proportions in certain fish oils. Eggs may contain predominantly either vitamin D_2 or vitamin D_3, depending on the feeding of the hen, but present trends in poultry husbandry are such as to increase the likelihood that vitamin D_3 will be the chief form present.

Nutritional Role of Vitamin D

As already indicated, vitamin D (if for convenience we may continue to speak in the singular in dealing with this factor) came to be known and has been studied largely through its involvement in the rickets problem.

Rickets (*rachitis*) is a medical term which does not always have exactly the same meaning in medical literature. Pathologists have until recently tended to follow Schmorl in defining rickets in terms of the histology of the growing ends of the bones, while pediatricians have more largely followed Park in defining rickets as a condition of retardation (or suspension) of the normal calcification of the developing bone.

As explained earlier in the chapter, the normal calcification (ossification) of the developing bone is essentially a building into the cartilaginous bone matrix of the crystalline bone mineral for which the chief ingredients are the calcium and the phosphate brought by the blood.

When the normal calcification of the growing and developing bone is retarded, an analysis of the blood quite regularly shows a subnormal concentration of calcium (calcium ion), or of phosphorus (phosphate), or both. It is logical to suppose that this subnormal supply of ingredients brought by the blood is in some sense a cause of the retardation of the calcification (ossification) process, although, as already mentioned, there may also (or in some cases) be a more "local" and less well defined factor involved.

This point of view recognizes both a low-calcium and a low-phosphorus type of rickets. Results of extreme (experimental) cases of low-calcium rickets are shown in Figs. 25 and 26. But only the low-phosphorus type shows the particular histology described in the classical work of Schmorl; so *some* writers have designated only the low-phosphorus type as true rickets.

How the subnormal concentration of calcium or phosphate ion in the blood comes about is not always clear. Such a shortage in the blood can sometimes but not always be attributable to a corresponding shortage in the food. More often, probably, it is attributable to a low "net absorption" of these elements: either too little getting in through the intestinal wall or too much passing out through the kidneys.

Vitamin D, whether taken as such or formed in the skin by irradiation with light of certain wave lengths (in the ultraviolet), tends to restore to normal the calcium or the phosphorus content

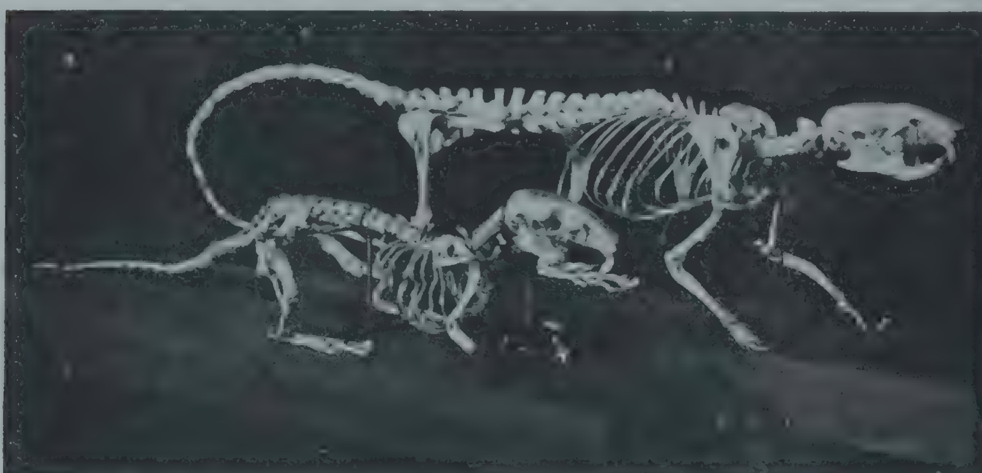

Fig. 25. Effects of very severe low-calcium rickets in contrast with normal twin brother. (Courtesy of the Journal of Biological Chemistry.)

of the blood, and the rate of calcification. As summarized in *Nutrition Reviews* for February, 1947, one present view is that "the action of vitamin D is to increase the 'net absorption' of the calcium and phosphate of the food, and is exerted in two ways. Directly, the vitamin D increases the permeability of the intestinal mucosa to calcium salts while leaving unchanged the permeability of other membranes. This leads to an increased serum calcium and consequently to a decreased activity of the parathyroid, thereby decreasing the rate of excretion of phosphate by the kidney. Vitamin D also appears to exert some direct effect on the calcification of growing bone; if large amounts of calcium and phosphate are supplied to the young rachitic animal by injection, then bone of normal density is laid down, but its histological structure is abnormal."

More recent studies directed to the local conditions in the bone and their relation to calcification and to vitamin D are discussed by Holman and McCance (1956) who suggest that both acid mucopolysaccharides such as chondroitin sulfate and a phosphatase occurring in the bone may be implicated; though they are forced to conclude that "the identity of the local factor in bone which appears to be necessary for the initiation of calcification has not yet been established."

Another effect of vitamin D which has been suggested recently is that it facilitates the utilization of the phosphorus of phytin under

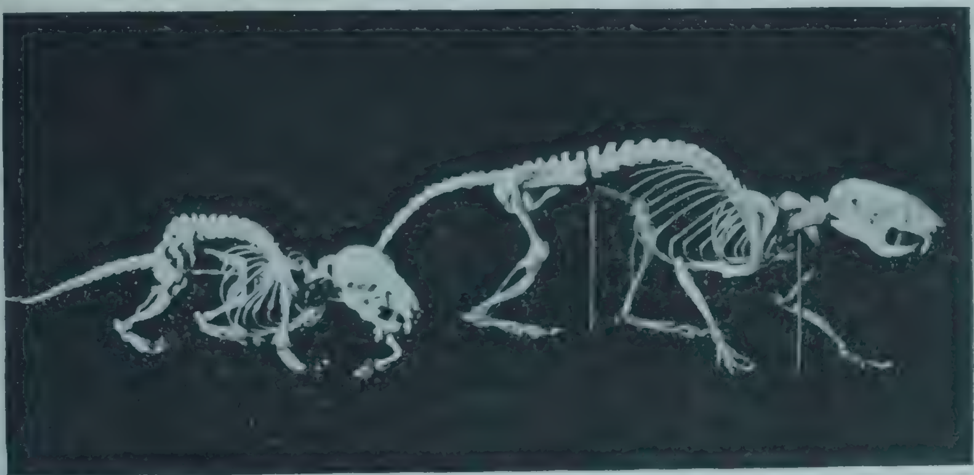

Fig. 26. Effects of very severe low-calcium rickets in contrast with a normal first cousin. Here with a dietary less drastically deficient, there appeared in the second generation the same skeletal difference as developed in the first generation in the case shown in Fig. 25.

certain conditions, although "the antirachitogenic effect of vitamin D cannot be explained solely on the basis of an increased availability of phytin phosphorus" (*Review*, 1956*a*).

That so many of the mild cases of clinical rickets are of the low-phosphorus type is largely if not mainly attributable to the fact that during the age-range in which rickets is most common there is a rapid growth of muscle and thus the baby's developing bones and muscles are competing for the phosphorus which the blood brings. To keep in mind the fact that a large proportion of the cases of the condition which we call by a pathological name (rickets or rachitis) may with at least as much reason be viewed as a matter of the rela-

tive rates at which two normal processes are proceeding, may serve greatly to clarify one's scientific view of the situation.

Severe rickets, while not fatal, may be a disease of tragic consequences; but at the other end of the scale (confusingly still called by the same name) are the "clinical signs" which Park says are "notoriously deceiving and cannot be relied on" because in fact they are merely the signs that one physiological aspect of development is making slightly more rapid progress than another.

Perhaps the most helpful view is that presented by Jeans and Stearns in the 1938 meeting of the American Institute of Nutrition, namely, that children differ in the efficiency with which they assimilate the bone-building elements from their food, and that vitamin D in some ways helps to improve the cases of low efficiency.

These investigators also emphasize the fact that even at levels above that of rickets prevention additional vitamin D may improve the rate of growth and development. This has also been found in controlled experiments with laboratory animals (Sherman and Stiebeling, listed in Suggested Readings).

Jeans and Stearns, in discussing their findings that amounts of vitamin D over and above those required to prevent rickets may have a further beneficial effect upon the retention of calcium and the linear growth of the bones, point out that this effect may not be noted in each individual but becomes evident when large groups are observed. Thus, studies of calcium retention in infants given no additional vitamin D showed marked variability in calcium retention with a low average. When amounts of vitamin D up to that supposed to be sufficient to prevent rickets were given, the number of low retentions decreased, raising the average retention of the group. A further and significantly greater increase in average retention was obtained (again by raising the lower limit of the retention range) when two to three times as much vitamin D was given as is required to prevent rickets. In somewhat older children, past the age where rickets is most apt to occur, Jeans and Stearns found that some showed efficient utilization and others poor utilization of the calcium of milk when no added vitamin D was given; and that supplying vitamin D tended to improve the calcium utilization by the latter group, whereas it had little effect on the former. With adolescence, however, the need for vitamin D became "as universal and as great as in infancy." Indeed, Johnston (1948) holds that, during

the period of rapid growth just before puberty, the need for vitamin D is probably twice as great as at any other time in life, except perhaps during the middle of the first year.

Measurement and Expression of Vitamin D Values

The *International Standard* for vitamin D is a crystalline preparation of vitamin D_3; and the International *unit* of antirachitic activity is defined as that exhibited by 0.025 microgram of this Standard material.

In spite of attempts to devise chemical assay procedures, principal reliance for the determination of vitamin D value still rests on tests with living things, prepared, fed, and examined in standardized ways. Since both types of method are undergoing development, those interested should consult the *current Pharmacopeia* and the *current volume* of the *methods* of the Association of Official Agricultural Chemists.

Sources

Irradiation. Herodotus wrote that sunshine is a potent factor in skeletal development; and an ancient Roman medical aphorism calls the Sun the greatest of physicians. But the importance of sunshine had to be rediscovered by Sniadecki in 1822 (as noted above), and again by Huldschinsky in 1919. When in 1924 it was found that natural foods, and (soon after) that certain sterols specifically, can be rendered antirachitic by irradiation, there rapidly developed a high enthusiasm for irradiated foods, and for irradiated ergosterol as a specific against rickets. But since (as explained early in this chapter) it has been found that the antirachitic substance produced by irradiation of ergosterol, or other plant sterol, is not the same as the natural vitamin D produced by irradiation of our skins, there has been some shifting back of emphasis from the irradiation of our foods to the irradiation of our bodies with direct sunshine containing its natural proportion of ultraviolet rays or with its carefully determined equivalent. The amount of vitamin D which may be formed in the body varies widely with such factors as affect the amount of active radiation that reaches the provitamin D in the skin. Sunshine is richest in actinic rays at times of year when, and

in latitudes where, the sun is most directly overhead. But much of this radiation may fail to reach persons living in smoke-palled areas, or in cities where crowded high buildings cut off much of the sunlight; and not all of the active rays can penetrate effectively the deeply pigmented skin layers of certain people. The benefit obtainable depends also directly on the amount of skin surface exposed, and thus varies both with the atmospheric temperature and with the habits of dress of the individual. Ordinary window glass stops most of the ultraviolet rays; but special glass which transmits them is now made, and is used in the construction of lamps which yield an indoor equivalent of "June sunshine" (i.e., of the brightest natural sunshine, at ordinary altitudes, of our temperate zone).

The same rays which produce vitamin D in the skin also increase the circulation, thus bringing a fresh supply of the precursor into the skin-layers where the transformation is taking place, and carrying the new-formed vitamin D promptly away from any danger of over-irradiation and into the service of the body as a whole, and particularly of the bones and teeth.

Fish oils. *Codliver oil* is outstanding in that it has been used as a remedy for rickets since the middle ages and is still universally prominent as a nutritional source of vitamin D. Liver oils from fish of the order Percomorphi (of which the blue fin tuna is a prominent member) are much richer in vitamin D, one of them having a reported concentration four hundred times that of ordinary grade codliver oil. As they are also very rich in vitamin A, such oils, available commercially as *Percomorph oil*, are becoming widely used. There are many persons for whom the fact that doses of this oil are measured in drops while those of codliver oil are measured in teaspoonfuls proves to be an irresistible advantage! *Halibut liver oil*, which is far richer in vitamin A than codliver oil, is only a few times more potent in vitamin D. For this reason, halibut liver oil to which viosterol has been added is frequently used where it is desired to give generous doses of both vitamins with a minimum volume of fishy-tasting oil.

The flesh of fish which contain much body oil, such as salmon, sardine, and herring, is a fairly rich source of the antirachitic vitamin.

Liver. The liver appears to be a principal site of storage of vitamin D in the animals commonly slaughtered for food; and the

consumption of calf, beef, lamb, and hog liver may thus be expected to contribute to the body supply of this factor. However, the amounts of vitamin D in liver depend upon the dietary and other management of the animal, and may vary down to practically zero.

Eggs. Hess showed in 1923 that the yolk of one egg contained enough vitamin D to serve as a daily allowance for the prevention of rickets in babies. The diet of the hens and the amount of ultraviolet light they receive both influence the vitamin D content of the eggs produced. In recent years the practical advantages of including fish liver oils or other sources of vitamin D_3 in the diet of laying hens have been increasingly realized and the practice has unquestionably resulted in bringing to the market eggs of higher average vitamin D value than those which proved such effective antirachitics in the early work of Hess.

Milk and its products: "Vitamin D Milk." The evidence varies greatly as to the vitamin D content of the fat of milk produced by cows on ordinary rations. *Vitamin D Milk* is the term generally used to indicate milk which has been enriched in its vitamin D value. Three methods of producing such vitamin D milk have been used commercially: (1) mixing into the milk a purified concentrate of natural (animal) vitamin, or, lately, of pure crystalline vitamin D_3 or D_2; (2) irradiation of the milk; (3) feeding irradiated material (usually irradiated yeast) to the cow. The first method gives a reproducible, high potency, and is increasingly preferred to the other two.

The practice of enriching milk with vitamin D is regarded with favor by most physicians and health commissioners, and has been given preferential endorsement by the Council on Foods of the American Medical Association in the following terms: "Of all the common foods available, milk is most suitable as a carrier of added vitamin D. Vitamin D is concerned with the utilization of calcium and phosphorus, of which milk is an excellent source. The Council has recently made the decision that for the present milk is the only common food which will be considered for acceptance when fortified with vitamin D."

"Vitamin D milk" is on regular delivery along with other fresh milk in many localities; and also a considerable part of the canned milk now offered in the retail market has had its vitamin D content enriched. In many cases, the vitamin D value is adjusted to 400

units per quart (of fresh bottled or reconstituted evaporated milk) so that the growing child who drinks his "quart of milk a day" is automatically assured the recommended intake of vitamin D.

An influential proportion of (though not all) pediatricians prefer vitamin D_3 to vitamin D_2, and also consider that vitamin D is best assimilated when consumed dispersed in milk.

Storage and Transfer of Vitamin D in the Body

The body is able, when supplied with abundant vitamin D, to build up large reserve stores of this factor, which may be drawn upon in later time of need. Some pediatricians have indeed advocated the administration of large doses under medical supervision two or three times a year, instead of relying on the mother's day-to-day dosage with fish oil or other preparation. Others tend to regard this as unnecessary in view of the educational campaign of the past three decades which has so successfully reduced the incidence of rickets; and as possibly undesirable in seeming to relegate vitamin D to the role of a medicinal agent rather than a normal nutrient.

It was shown many years ago with experimental animals that the maternal organism shares its vitamin D with the offspring both before birth and later through the milk. A liberal intake of vitamin D during pregnancy and lactation thus serves the double purpose of giving the baby a body store of the vitamin and of assisting the mother to use her dietary calcium and phosphorus efficiently to meet the extraordinarily heavy demands of these periods.

Human Requirements for Vitamin D

It follows from what has been said that the proportion of the total vitamin D required in metabolism which must be provided by the diet may vary enormously from individual to individual, depending on the opportunity which each has for synthesis of this factor in his body by irradiation.

Vigorous adults, leading a normal life, are thought to require little if any supplemental vitamin D, and no dietary allowance is made for them in the National Research Council recommendations. It is, however, suggested that: "for persons working at night and for nuns and others whose habits shield them from sunlight, as well as

for elderly persons, the ingestion of small amounts of vitamin D is desirable."

For women in the latter part of pregnancy and for nursing mothers, supplemental vitamin D is recommended, 400 units being regarded as "probably adequate . . . on the basis of available evidence."

The newer view that, in addition to infants, most growing children and all adolescents require liberal amounts to achieve satisfactory calcium retention is reflected by the extension to all age groups below adulthood of the recommendation that this be insured by supplying 400 units daily in the diet. The discussion accompanying the Recommended Allowances implies that enough vitamin D to promote maximal calcium retention is the objective; and states that 300 to 400 units per day have been shown to be ample for most infants; while the actual requirement at later ages has not been determined as accurately. "It is known, however, that 400 units daily is ample for good calcium retention in children when the milk intake is appropriate. . . . The total (daily) amount required in adolescence probably is no greater than in infancy." It is doubtful how much, if any, supplementary vitamin D is needed by adults living under normal conditions of diet and of exposure to sunlight.

It follows from what has been said above that no simple quantitative statement of the vitamin D requirement of human nutrition could as yet represent a complete consensus of opinion. For vitamin D is formed in the body in widely variable amounts depending on the duration and effectiveness of the irradiation to which the skin is subjected. Then, too, the different molecular forms in foods and medicinal sources may vary (and, if so, to an extent not yet definitely measured) in their efficacy in human nutrition, and even the same chemical form may have different efficacy according to the medium in which it is taken. There are also differences of view as to the extent to which the amount required for optimal growth exceeds the amount required for the prevention of rickets; and it seems certain that under the same conditions some children need more than others.

EXERCISES

1. Induce rickets in rats by means of the Steenbock rickets-producing diet described in the current United States Pharmacopeia; or that of

Zucker and coworkers in the paper listed among the Suggested Readings below. Arrange, if possible, for x-ray photographs. Otherwise, begin the experiment while the rats are small and see whether the rickets become obvious to naked-eye examination, either of the live rat or of its skeleton.

2. Induce low-calcium rickets by diet of low-calcium foods without provision for vitamin D either as such or as light. Save the skeletons of such rachitic rats as a permanent exhibit.

3. Examine the literature: (*a*) for evidence as to the relative values of vitamins D_2 and D_3 for children; (*b*) for advances in knowledge of any of the other vitamins D.

4. Compile and discuss current estimates of the vitamin D requirements of human nutrition.

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17

OTHER FAT-SOLUBLE VITAMINS

Vitamin E

Although vitamin E is one of the longer-known vitamins, its existence having been recognized in the early 1920's, it is still not possible to define clearly the role of this factor in human nutrition; and for this reason a brief treatment only of it is appropriate to this book.

At least four chemically identified naturally occurring substances (known, respectively, as alpha-tocopherol, beta-tocopherol, gamma-tocopherol, and delta-tocopherol), as well as a number of related synthetic compounds, possess the activity ascribed to vitamin E.

The vitamins E are fat-soluble materials, found along with the fats in grains, vegetables, meat, milk, and butter, and doubtless occurring very widely among food materials of both plant and animal origin which have not been artificially refined. Toward heating and many other adverse influences, the vitamins E are among the most stable of the known vitamins. But treatments which cause the fat with which vitamin E is associated to become rancid result in rapid loss of this factor.

An outstanding chemical property of vitamin E is its antioxidant action, which tends to "protect" or "stabilize" unsaturated fats and certain other oxidizable substances including vitamin A and carotenes -not only in food sources but also, to some extent, within the body, both in the alimentary tract and in the cells. This is of practical importance on marginal intakes of vitamin A. A still more specific effect for alpha-tocopherol in tissue oxidations, viz., as activator of cytochrome c reductase, is suggested by recent work of Nason and Lehman (1955), though final proof is lacking.

Deficiency of vitamin E in rats manifests itself characteristically by reproductive failure in both sexes. In the deficient female, estrus,

ovulation, and impregnation of the ovum occur normally, but the fetus dies and is resorbed before maturity is reached. Treatment with vitamin E restores the ability of the female rat to bear normal young. In the male rat, on the other hand, deficiency of the vitamin may cause apparently irreparable degeneration of the germinal epithelium, with resulting complete and permanent sterility.

The effects of a lack of vitamin E are not, however, limited to the reproductive organs. The symptoms most prominent vary from species to species, and with the age of the individual, but in one or another species may include failure of growth, muscular dystrophy, injury to the central nervous system, interference with normal heart action, and possible endocrine disturbances.

Whether the counterpart of any of these conditions occurs in human beings is still controversial. In any case vitamin E is so widely distributed among different types of food that there should be little likelihood of its being a limiting factor in human beings. Consequently, it seems unnecessary and quite possibly misleading to lay emphasis on vitamin E in practical consideration of food values.

Synthetic alpha-tocopherol acetate has been adopted as the International standard for vitamin E; and the International Unit has been defined as the specific activity of 1 milligram of the standard preparation.

Vitamin K

Vitamin K ("Koagulations-Vitamin") was so named by the Danish workers Dam and Schønheyder to connote its relation to the coagulability of the blood, through which they had discovered its existence. When insufficient vitamin K is available there ensues a decrease in the blood concentration of *prothrombin*,[1] one of the constituents necessary to the clotting process, with resultant lengthening of the time required for coagulation. This condition of *hypoprothrombinemia* occurs quite frequently in human beings who have disturbances of the bile tract. In those cases the diet, as a rule, is not primarily at fault, but, owing to lack of bile in the intestine, there is poor absorption of fat and hence of fat-soluble vitamin K.

[1] It will be remembered that prothrombin is a precursor of thrombin, which in turn is necessary to convert fibrinogen to fibrin, the principal constituent of the blood clot.

The remedy for such persons is either to inject vitamin K, or to feed it together with bile salts.

A considerable degree of hypoprothrombinemia appears to be common in newborn babies: and in some babies this is so very marked as to cause serious danger from hemorrhage. Though the reason for this condition is not fully understood it has been shown that administration of vitamin K to the newborn child (or even to the mother shortly before the birth) significantly raises the blood prothrombin value in the first days of life. One or the other of these precautionary measures has now been adopted by many obstetricians and maternity hospitals, with resultant sharp drop in the incidence of hemorrhage in the newborn.

To what extent, if any, there is a vitamin K problem in nutrition in the sense of feeding people we do not yet know. But vitamin K is widely distributed among many different kinds of food (though especially abundant in green leaves) so that we should expect dietary deficiency of this factor to be rare. In addition, it has been suggested that vitamin K is normally formed by the intestinal microorganisms in such quantities that "the only times when the human intestinal flora does not produce enough vitamin K for human needs appears to be immediately after birth before the intestinal flora is established, and possibly during prolonged treatment with sulfa drugs" (*Present Knowledge in Nutrition*, 1956, page 74).

Though we have here referred to vitamin K in the singular, it should perhaps be mentioned that at least two forms (K_1 or phylloquinone, and K_2) occur naturally, and that a number of chemically related synthetic products have also the antihemorrhagic properties of vitamin K.

Possibility of Other Vitamins

There is no general agreement as to how widely the term vitamin shall be used. And certainly there is no attempt to mention in this book "all the vitamins there are."

EXERCISES

1. Study the available literature published since the foregoing text was written (1956) and write a supplement bringing it up to date.

2. The essential fatty acids are sometimes spoken of as a vitamin factor. Write a section similar to those above, regarding our present knowledge of this factor in nutrition.

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18

SOME RELATIONS OF FOOD TO THE TEETH

Introduction to "the Tooth Problem"

The formation of good teeth, and the maintenance of the health of the teeth and gums, present such special and such baffling problems that any attempt to treat this subject here will necessarily lack conclusiveness of scientific explanation.

Yet while the teeth and adjoining tissues are quite unique structures they still are a part of the bodily structure, and like the rest of the body they are considerably influenced by the food.

Some relations of food to good teeth are now sufficiently established to warrant our attention, even though we have not yet a clear consensus of opinion as to the precise explanation of all the facts.

Broadly speaking, a tooth is made up of four main sections: the *enamel* or outer covering, the *dentine*, the *cementum*, which covers the dentine below the gum surface, and the *pulp*. (Fig. 27.) In the perfect tooth, the enamel is hard, brittle, and semitransparent, and presents a smooth, lustrous appearance. It is non-cellular and is built up of prisms united by a densely calcified intermediate substance. The enamel forms a comparatively thin layer or cap over the dentine, which makes up the largest portion of the tooth. The dentine is a yellowish-white, translucent substance resembling bone, and consists of a non-cellular, homogeneous material traversed regularly by branched socalled dentinal tubes, which contain projecting outgrowths from the dentine-forming cells, together with nerves, some tissue fluid, and other organic matter. The innermost portion of the tooth, the pulp, is a soft tissue, composed largely of cells, blood vessels, and nerves. Its outer layer consists of *odontoblasts*, or dentine-forming cells; and in young, growing teeth there is always

between the pulp and the (calcified) dentine a layer of uncalcified matrix, penetrated by fibers from the odontoblasts, which is the zone where further calcification is taking place. Normally, this zone is quite thin, but in an imperfectly calcified tooth, it may be wide and irregular and patches of uncalcified material known as "interglobular spaces" may remain as permanent defects in the resulting dentine. The imperfectly calcified tooth may also show defects of the enamel, varying from slight roughness to deep pits and grooves, and even in some cases to a complete absence of enamel over certain areas.

The term *hypoplasia* is frequently applied to such conditions of poor structural development of the teeth, which are to be distin-

Fig. 27. Section of a normal molar tooth, showing the enamel (E), the dentine (D), the cementum (C), and the pulp (P). (Courtesy of Dr. Charles F. Bodecker.)

guished from *dental caries*, or actual decay and disintegration of teeth already formed. The making of this distinction, however, should not be taken to imply that these two types of tooth trouble are entirely independent of each other, for even slight defects of structure may constitute a starting point for the development of caries. And complete perfection of tooth structure is not common.

Marshall (1939) considers it a "confirmed clinical and laboratory observation" that there is scarcely a tooth in man or lower animal which does not present areas of incomplete formation. Hence much depends upon the "personal equation" of the investigator in all studies of the incidence of tooth defects; for some will call a tooth

defective while others, equally expert but of more tolerant temperament, will pass it as normal.

Marshall's view, following that of Fish, is that caries begins in a permeable crevice or fault area which after eruption of the tooth becomes filled with the fluid and suspended materials in the mouth, which from time to time include food particles and bacteria (see Fig. 28). Among the latter are those whose products tend to corrode the tooth. If this corrosion is not too rapid, the slight irritation of underlying dentine which it causes may result in a sufficiently augmented calcification from within to erect an effective barrier

Fig. 28. Section of a tooth in which caries (C) has begun to develop in a deep fissure of the enamel. (Courtesy of Dr. Charles F. Bodecker.)

against further invasion of the tooth by the caries. Current writings stress the importance of the *dental plaque* in initiating a lesion in what may have been originally sound enamel. Plaque formation appears to be favored by insufficient cleansing of the tooth surface (and so to be more common where the tooth surface is pitted or irregular) with the result that food particles, bacteria, and other mouth debris adhere to the surface. Within the plaque, conditions are favorable to bacterial formation of products which attack the enamel, especially if the diet provides liberal amounts of carbohydrates which can penetrate the plaque. The importance of the latter factor is emphasized by observations on primitive populations which show that, on diets low in fermentable carbohydrates, teeth may remain sound even though plaque formation is extensive and the enamel fissured (see Fig. 29).

Although attempts have been made to study the incidence of

hypoplasia as such in human teeth in order to correlate this with what was known of the nutritional background, these efforts have frequently been confused by the difficulty of recognizing hypoplasia in the presence of caries. In studying this aspect, therefore, frequent use has been made of the puppy as an experimental subject: for, as Blunt and Cowan point out, the dog (unlike the rat or the guinea-pig) resembles the human being in that he forms two sets of teeth, temporary and permanent, which in their growth and development are readily comparable to those of man. Although hypoplasia resembling that of human teeth may be developed in dogs by dietary

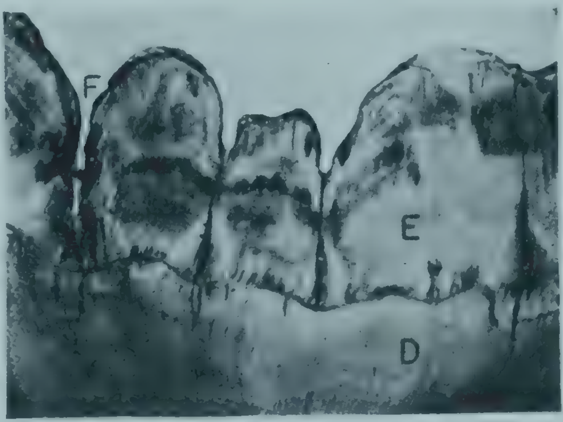

Fig. 29. Section of a tooth of a Pueblo Indian living more than 900 years ago, showing deep enamel fissures (F) but no caries. (Courtesy of Dr. Charles F. Bodecker.)

mistreatment, actual decay does not occur commonly in this species, and hence one may investigate the former condition practically uncomplicated by the latter.

Lady May Mellanby reported extensive investigations of the teeth from the puppies with which her husband was studying experimental rickets. Her studies leave no doubt that tooth structure is markedly influenced by nutritional conditions prevailing at the time the tooth in question is being formed, whether before or after birth. There are indications, however, that the body resources of the mother may serve to a limited extent as a factor of safety, so that poor diet of the mother before birth is somewhat less disastrous in its effect on her child's teeth than is correspondingly poor diet of the infant after birth.

Even where a tooth seems normally calcified, there are differences in chemical composition, such as its fluoride content or its mineral composition, which may affect the susceptibility to decay.

Some of the Causes of Tooth Defects

Because defects of structure are so closely connected with the caries problem, Marshall's classification, while offered in connection with his writings on caries, is broad enough for the present purpose. "For convenience" he groups the causes alphabetically as follows: A, anatomical; B, bacteriological; C, chemical; D, dietary; E, endocrine; F, failure in mouth hygiene; H, heredity. And he (1939) holds that the relative importance of these seven groups of factors varies "with age, environmental vicissitudes, habits, health, and probably other, as yet undetermined, agents."

Also it is to be remembered that these causes probably more often act two or more together than any one separately. In fact, the "chemical" causes are presumably most often results of bacteriological or dietary causes, or of such failures in mouth-hygiene as inadequate cleansing or the use of corrosive dentifrices. On the other hand, one may be born with some tooth defect or susceptibility to caries bacteria which cannot in any known way be connected with his heredity, and might be classified as idiosyncratic or due to Chance (an alternative C for Marshall's classification in case you consider "chemical" as covered by other causes).

Kesel (1943) classifies the factors in the development of caries into two major divisions: (1) the exciting factors, which actually produce the lesion; and (2) the predisposing factors, which permit the exciting causes to exist and operate. The actual exciting causes are few, as viewed by Kesel, probably only two: first, bacteria within a plaque on the tooth surface capable of destroying tooth surface by the products of their metabolism; and second, material on the tooth surface or in the mouth capable of being converted into substances harmful to the tooth. Without these two conditions, Kesel believes, caries in all probability could not occur. Yet all individuals have bacteria on the tooth surfaces, and most of them, at times, have upon their teeth or in the mouth, materials that these bacteria could utilize to form acid. Since all teeth do not become carious, there must be other circumstances which determine whether or not damage to the teeth occurs. These are what Kesel calls the *predisposing* factors, and classifies into two groups: (*a*) factors which exert influence through systemic or nutritional

channels, and (*b*) local factors, which have their effect through the immediate environs of the teeth. Since the chemistry of the saliva, an important environmental factor, is under systemic control (and varies with the blood chemistry) it is seen that (*a*) and (*b*) overlap at points.

Still another way of grouping factors which influence the teeth would be according to the stage at which they operate: whether during the period when the tooth is forming and maturing, or after it is erupted and fully developed. Recent work with radioactive isotopes indicates that certain ions at least can penetrate to all parts of the tooth, both from the pulp and from the saliva, emphasizing that changes may occur in the chemical composition of already formed teeth, as a result of dietary or other influences, to a greater extent than was formerly considered likely.

As will be apparent in the discussion which follows, the factors and their modes of operation overlap so as to make clear differentiation and interpretation often difficult or impossible.

Empirical Evidence That Food Is a Factor

Some years ago a group of diabetic children, who had long been receiving special care as to diet, were found to have unusually good teeth.

A large-scale trial with abundant controls was later made by feeding a part of the population of a large orphanage with a diet containing (as had that of the diabetic children) "liberal amounts of milk, eggs, meat, fresh and canned vegetables and fruits, and codliver oil daily." This also led to a great decrease in the incidence of tooth defects among the children of like age in the same institution. Speaking of more recent extensions of these studies, where caries was again strikingly arrested by dietary regulation, Boyd reported in 1942 that neither the high-fat nor the low-sugar content of the early diabetic diet appears to be essential to this effect on the teeth; and concluded: "We have been unable to attribute this favorable effect of the dietary regimen to any single constituent or characteristic of the diet."

It may perhaps be of interest to add the following incident which came to the knowledge of one of us while serving as a member of the advisory committee to a comprehensive dental research. One

aspect of this research was to be a fairly large-scale attempt to improve the teeth of children in institutions, by certain nutritional enrichments of their dietary under conditions of experimental control, and with exceptionally careful and expert examination of the teeth before and after the dietary tests. A certain institution with a child population of about 400 seemed when first briefly visited to be a promising place for such experiment because the physical circumstances permitted of good control, the management was scientifically-minded and cooperative and the income of the institution was so meager that the proposed gift of "protective" foods for the nutritional experiment would have been extremely welcome. But the research dentist found in the first examination of these children's teeth that there was *so little room for improvement* that this group of children would not do for his investigation after all! And his explanation was that the institution, while financially in difficult circumstances, had for some years had a good dietitian so that the children had already had the benefit of the sort of diet he had intended to try, and had only a fraction of the incidence of dental defects commonly found in American children of their age.

In this case the dietitian had been guided, not by any special theory as to the tooth problem, but by the general principles of the newer knowledge of nutrition. This institution population illustrated well the *trend* which Dr. Percy Howe expressed in the saying that, "*Generally*, good health and good teeth go together."

Undoubtedly, as the guidance of the newer knowledge of nutrition comes to be accepted more and more widely and wholeheartedly, dental health will be improved along with the health of the body as a whole. Yet we seem to meet enough people whose dental health is below the level of their general health, to constitute a scientifically valid indication that "there is something special about the teeth and gums." Does study of them indicate need of special emphasis on certain nutritional factors? Does it also indicate that diet has other than strictly nutritional relations to the health of the teeth?

Individual Nutritional Factors

Calcium and *phosphorus* are such prominent ingredients of the chief tooth mineral that they must certainly be regarded as among the major nutritional factors concerned in the building of good

teeth. This must be emphasized; for the fact that these elements do not tell the whole story, and the further fact that, once built into the tooth structure, they are not very readily withdrawn by the circulation, have resulted in too great a tendency to ignore them in recent discussions of the tooth problem. For the construction of good teeth, the body needs, on the one hand, abundant supplies of calcium and phosphorus as building material; and, on the other hand, abundant supplies of such vitamins as regulate the processes involved in building these particular tissues. These latter include vitamin D certainly, and, if observations on animals carry over to man, vitamin C and vitamin A as well.

Even after the period of tooth formation, a favorable intake (and balance) of calcium and phosphorus apparently continues to have a beneficial effect in arresting caries. For Cox[1] writes: "No one has shown the concurrent existence of dental caries activity and good retention of calcium and phosphorus."

That the calcium intake may indeed frequently be a limiting factor in tooth soundness was suggested by the finding of East (1941) in a survey of 109 cities in the United States, that hardness (richness in calcium carbonate) of the city water supply was associated with lower-than-average incidence of caries in the school children; and strikingly confirmed by extended studies among South African groups, where allowance was made in addition for a possible fluoride effect.

Vitamin D. The essential similarity between the various calcified structures of the body, and the demonstrated importance of vitamin D to the development of the bones, lead naturally to the problem of the extent to which the teeth also are affected by this factor.

It has long been accepted that rickets occasions a *delay in dentition;* and Hess has cited an investigation in his clinic which showed that even in cases of extremely mild rickets teething was retarded, for "whereas about one-half the number of normal babies developed a tooth between the sixth and the ninth month, only about one-fourth of the infants with mild rickets had a tooth at this age." The eruption of subsequent teeth was likewise tardy. Clearly then the provision of vitamin D in a sufficient quantity to prevent all

[1] Page 482 of *Survey of the Literature of Dental Caries,* Publication No. 225 of the National Research Council, 1952.

rachitic manifestations may be expected to hasten somewhat the time of appearance of the baby's teeth.

Proceeding now to a consideration of vitamin D in relation to dental caries, two questions suggest themselves: (1) to what extent does hypoplasia (of which, as Lady Mellanby's experiments showed, lack of vitamin D is one cause) predispose to caries; and (2) once the teeth have been formed (for better or worse), what protection, if any, against the inroads of tooth decay, may be hoped for from a liberal intake of vitamin D?

With regard to the first question, it would seem logical to expect that, whatever the underlying cause of caries, the damage, which involves essentially the solution of calcium salts by agents reaching them from outside the tooth, will be more severe to the hypoplastic tooth in which the protective coating of enamel may be less dense, or pitted and grooved (making mechanical removal of the destructive agent more difficult), or even totally lacking in spots; and in which the interglobular spaces of the dentine facilitate further penetration by the disintegrative fluid.

This reasoning is substantiated by the clinical experience that those teeth and portions of teeth which are in general most apt to be hypoplastic (perhaps because of the period of life at which they are calcified) are likewise in general most liable to dental caries. Thus, for example, Dick found in an investigation of the permanent teeth that, of the cases with carious teeth, the lower first molar was decayed in 80 per cent and the upper first molar in 30 per cent. The fact that the lower first molars decay out of proportion to the others "is to be attributed rather to the main part of the enamel of the crown having been laid down in the first two years of life when rickety conditions are operative." And Lady Mellanby, correlating structure with decay in individual teeth, found that those which were normal or nearly normal in structure had carious cavities in only a little more than one quarter of the cases, as compared with 85 per cent incidence of caries in distinctly hypoplastic teeth.

On the other hand, it is well known also that many hypoplastic teeth remain resistant to caries throughout life. Clearly, there are other factors to be considered in the problem of caries besides the structural quality of the teeth.

Administration of vitamin D was found by Mellanby and other workers to protect already erupted teeth significantly against the

development of new caries in children, and to arrest previously existing carious lesions.

In the work of Boyd, Drain, and Stearns it appeared that a change of diet in the general direction indicated by the newer knowledge of nutrition reduced the rate of caries development in children, and that a further improvement was then effected by increasing the vitamin D intake to 600 units per day. This effect of 600 International Units per day was, however, stated to be no greater than that observed in other work by them with 350 International Units per day; so that the National Research Council's recommendation of 400 International Units per day should permit an optimum effect of vitamin D on the teeth.

The vitamin D derived from sunshine may also affect importantly the soundness of the teeth. Thus, Mills (1937) found that, progressing northward across the United States, there was a steady increase in the frequency of caries among school children, which amounted in all to over 200 per cent increase from the Gulf of Mexico to the Canadian border. And East reported that the frequency of dental caries in various portions of the country varied inversely with the annual hours of sunshine enjoyed in the different regions.

According to the Council on Foods and Nutrition of the American Medical Association: "There is clinical evidence to justify the statement that vitamin D plays an important role in tooth formation. Likewise experimental evidence justifies the statement that vitamin D is a beneficial factor in preventing and arresting dental caries when the intake of calcium and phosphorus is liberal and the diet is adequate with respect to other nutrients."

Vitamin C. In the days when severe scurvy was common, it frequently resulted in loss of teeth, though available records do not make clear in how far this was due to an effect upon the tooth itself and in how far to the condition of the gums and jaw bones.

In 1919, Zilva and Wells in England studied microscopic sections of the teeth of guineapigs subjected to shortage of vitamin C and came to the conclusion that the tooth is one of the first, if not the first, of the parts of the body to be affected by subnormal intake of this vitamin, and that profound changes may occur in the teeth even when the ordinary scorbutic symptoms are still so slight as to be almost or quite unrecognizable. (There were at that time no

means of measuring the level of concentration of vitamin C in the body.) The typical effect upon the teeth was described as a fibroid degeneration of the pulp with a replacement of the fine structural organization by amorphous material. Similar degeneration was noted by Westin in the teeth of scorbutic human beings; but clear-cut evidence is lacking that this increased the susceptibility to dental caries.

In 1920 Howe of the Forsyth Dental Clinic and the Harvard Department of Pathology also found that scorbutic diets have a deleterious effect upon the teeth. He noted a marked decalcification and loosening of the teeth, with absorption of the alveolar processes as in pyorrhea; and emphasized the finding that if the condition was not too far advanced it could be cured by simple addition of orange juice to the diet. Others have also emphasized the good effects of orange juice upon the health of the teeth and gums. Höjer's very extensive studies, both experimental and clinical, seem to leave no doubt that even mild degrees of shortage of vitamin C are very important.

Boyle, Bessey, and Wolbach (1937) of the Harvard Dental and Medical Schools, in carefully controlled experiments with individual vitamin deficiencies, find that shortage of vitamin C may bring about a condition which upon full pathological investigation appears to be identical with one of the well-recognized clinical forms of pyorrhea: pyorrhea of the systemic type.

Particularly noteworthy is the further fact that these investigators then examined patients in the dental clinic and found definite correlation between this type of pyorrhea and a low concentration of vitamin C in the blood.

McCollum points out that dentine is derived from the mesoblastic tissue; and holds that the odontoblasts, which form dentine, are extremely sensitive to deficiency of ascorbic acid, so that if the tissues become depleted of this substance while the teeth are in process of growth, defective dentine will result.

Vitamin A. Markedly abnormal tooth structure, involving especially the enamel, was found by Wolbach and Howe and later workers to be a prominent feature of vitamin A deficiency in experimental animals. McCollum *et al.* (1939) hold that the enamel-forming cells (ameloblasts) are derived from the same embryonic tissue (ectoderm) from which gum epithelium has its origin; and

that they should therefore logically be expected, like other epithelium, to be extremely sensitive to deficiency of vitamin A.

Although the Committee on Dental Health of the Food and Nutrition Board could (1952) find "no evidence except the one case described by Boyle to show that vitamin A deficiency in man resulted in a malformation of the teeth," and further, "no direct evidence that the addition of vitamin A to a diet will reduce dental caries incidence," the evidence of animal experimentation strongly suggests that vitamin A is indeed a factor in the building of sound teeth, and points to the desirability of more controlled human observations. The further possibility that vitamin A deficiency may affect the flow of saliva and so affect the caries incidence has been suggested.

Sugar Intake and the Teeth

The view was advanced by Bunting, Koehne, and others that an increased intake of sugar results in an increase in the number and severity of carious lesions in teeth already formed; and that this is due to the effect of soluble carbohydrate in promoting the multiplication in the mouth of types of bacteria which are specifically bad for the teeth.

Recent evaluations of the effects of wartime diets, notably low in sugar and refined flour, on the teeth of European populations lead to the further suggestion that such diets may have an even more marked beneficial effect in promoting the development of teeth which are less susceptible to decay than teeth which form under ordinary peacetime conditions. For, observations on caries incidence among three-quarters of a million school children examined in eleven European countries in the past forty years consistently point to a decreased incidence of tooth decay toward the latter part of, and following, both World Wars I and II. The decreased tendency to caries did not appear clearly until more than a year after the wartime diet was begun, and it was still evident for several years after the close of the war and return to ordinary food habits. Moreover, the beneficial effect was most striking in young children and in *those teeth* of older children which developed and matured during the war years.

Such observations seem to indicate that the tooth structure itself —and not merely the environment in the mouth—benefited in some

way by the enforced restrictions of wartime diet. Whether this came about directly as the result of a low sugar intake or because the quality of the diet improved when other "natural" foods had to be taken in place of the refined carbohydrate, or in some still other way, is not certain. However, animal studies confirm the belief that a high sugar intake is specifically bad for the teeth, especially when conditions are such that the carbohydrate remains in the mouth for some time.

Favorable Effects of Certain Fruits and Vegetables

The eating of fruit, particularly raw fruit such as apple, or taking orange or grapefruit juice, at the end of a meal or soon after, or at bedtime, is considered by some investigators to induce "a bacteriostatic condition in the mouth."

Precise explanation of this benefit is not yet entirely clear. It may be a combined effect of several factors no one of which sufficiently predominates over the others to be readily demonstrated in an outstandingly convincing way.

In the case of such a soft-fibrous texture as that of a raw apple (or of celery) the mechanical effects of moderate massage of the gums, and of leaving the surfaces of the teeth scrubbed free from food particles, are in themselves beneficial. The "savory" property of such a raw food or of a citrus fruit juice doubtless also means a physiological stimulation of the cells which pour their more or less bacteriostatic secretions into the mouth. Again, some investigators have emphasized the view that the mild acidity of a fruit or fruit juice is helpful in keeping the tooth surfaces free from plaques and in affording a wholesome stimulation of the mucous membranes of the mouth, in contrast to the unnatural and drastic "cleansers" of some tooth pastes, which may be injurious.

Fruits and vegetables generally, and milk, cream, and ice cream, tend to the ensurance of good intakes of calcium, phosphorus, vitamin A, and vitamin C; while eggs are a good source of phosphorus, vitamin A, and vitamin D. Hence liberal use of these foods may reasonably be expected to aid both the development and maintenance of sound tooth structure and a healthy condition of the gums.

Fluorides and the Teeth

Opinions may differ as to whether any discussion of the relation of fluorides to the teeth is appropriate to a nutrition textbook, or whether this should be regarded as purely a public health problem. For this reason, a brief statement only will be given here of the findings which recently have attracted much attention from the dental profession and the general public.

The discovery by Smith, Lantz, and Smith (1931) of the cause of mottled enamel is of closely related interest to the influence of food upon teeth and also illustrates the important fact that the methods of long-time feeding trials under strict laboratory control developed in nutrition research may also be uniquely useful in solving problems of the relation of our intake to our health which may be other than strictly nutritional.

Upon careful investigation by Margaret Cammack Smith, chief of research in human nutrition of the University of Arizona, the defect of human teeth known as mottled enamel was found to be due, not to a nutritional deficiency, but to injury of the teeth by the fluorine of the local drinking water. Later, surveys showed that mottled enamel is endemic in many regions throughout the world, and is invariably associated with drinking water containing about 1.5 or more parts per million of fluorine. Communities nearby but with fluorine-free water supplies, have natives free from this disfiguring defect of the enamel. Studies of the teeth of migrants into and from high-fluoride regions indicate that this effect of fluorides operates during the developmental period only and is not reversible: teeth are mottled or not depending on the fluoride intake while they are being formed, and, once mottled, they remain so.

A decade or so ago, however, a different sort of emphasis began to be directed to the fluorine problem, viz., whether a certain intake of the element may not be beneficial in protecting the teeth against decay, whether perhaps there may be more water supplies with suboptimal levels than with excessive concentrations of fluoride. H. T. Dean, at the National Institute of Health, and others, amassed impressive statistical evidence that tooth decay is less extensive among natives of communities where the drinking water contains

fluoride than among those of fluoride-free districts, and that this "protective" effect may be noted even on fluoride levels below those which produce mottled enamel. Persons who had resided in "fluoride localities" during the period when their teeth were developing were found to retain a *relative* immunity to tooth decay through years of subsequent residence in fluoride-free areas. Application of fluorides, several times a year, to the surface of the teeth, especially in young subjects, was reported by several dentists to reduce the incidence of new caries strikingly. How this effect is produced is not certain, but evidence has been presented suggesting: (1) that fluoride hardens the enamel and makes it more resistant to acid (or other) erosion; (2) that it decreases the number of mouth bacteria supposed to be harmful to the teeth; and (3) that it may furthermore diminish acid formation by these bacteria.

Such observations have led naturally to the question whether it may be possible to reduce the tooth decay of whole communities by simple addition of fluoride to the public water supply. Simultaneously arises the question whether even small amounts of a potentially toxic material such as fluoride may be ingested day in and day out without risk of injury to other body organs. A comprehensive investigation of both questions was conducted under the auspices of the New York State Department of Health in the two communities of Newburgh and Kingston, New York. These neighboring cities are of similar size, population groups, economic status, have common sources of food supply, and, until May of 1945, the water supplies of both were "fluoride-free." Dental examination of all school children 5 to 12 years old revealed the same situation in both cities—an incidence of 21 decayed, missing, or filled (DMF) teeth per 100 *permanent* teeth. Since May, 1945, fluoride has been added to the Newburgh water supply, bringing the level up to 1.0–1.2 parts per million, while the Kingston water supply has remained "fluoride-free."

Periodically since then the children living in the two communities have been given dental (and also physical) examinations. The results of ten years' observations recently published (Ast, *et al.*, 1956) show an unmistakably favorable effect of fluoridization on the teeth of the children in the community. The effects were greatest in those children who had received fluoridated water during their entire lives, and in those teeth of older childen which were

still in process of development when fluoridization was begun. Thus, in the case of the first permanent molars of children in Newburgh who were 6–9 years old in 1954–55 and who had been exposed to fluoridated water since birth, the incidence of decayed, missing, or filled teeth was 52.9 per cent less than for the same age group who had grown up in Kingston where the water supply was practically fluoride-free; children 10–12 had 29.8 per cent lower DMF rate; while children 13–14 (the crowns of whose first molars were already calcified in 1945 when fluoridization started) had a 14.2 per cent lower DMF score; and even the 16–year olds, whose first molars were either erupted or about the erupt in 1945, benefited to the extent of about 4 per cent when the incidence of teeth which were decayed, missing, or filled is compared with that for the same age group in nearby "fluoride-free" Kingston. Among the second permanent molars, which in the case of children who were 13 or 14 years old in 1954–55 had just been starting to develop when fluoridization was initiated, the incidence of decayed, missing, and filled teeth was reduced 51.2 and 44.2 per cent, respectively; and the 16–year olds, whose second permanent molars had been about half developed when fluoridization started, had 28.7 per cent lower DMF score in these teeth than 16–year olds in Kingston. Though effects on the permanent teeth are naturally of greatest significance, it is also of interest and importance that there were *six times* as many children 6 to 9 years old in Newburgh who had all their deciduous cuspids present and caries-free, as in Kingston.

Similar fluoridization study projects in other cities in the United States and Canada have yielded strikingly similar results.[2]

No undesirable systemic effects were detected in thorough medical examinations of children in Newburgh (as compared with those in Kingston) or in statistics on adult mortality (Schlesinger, *et al.*, 1956). And Hodge (1956), reviewing the available evidence on human fluoride metabolism, states: "When all the evidence is put together, it may be concluded that in water fluoridation adequate factors of safety exist against the known toxic effects of fluoride. Additional studies are needed of population groups that have been for many years drinking fluoridated water." Pending the latter,

[2] A compilation of the findings is given on p. 3 of the National Research Council's publication No. 294 (1953) entitled *The Problem of Providing Optimum Fluoride Intake for Prevention of Dental Caries.*

there are still some who reserve final judgment as to the safety of water fluoridization. Meanwhile, even the most enthusiastic supporters of the policy admit that it cannot be expected to eliminate all caries, and nutrition will undoubtedly continue as a factor.

In Conclusion

From the strictly nutritional viewpoint, there appear to be at least five factors important to good teeth and gums: calcium, phosphorus, and vitamins D, C, and A. If much of the nutritional investigation of dental problems seems inconclusive, this is probably largely due to attempts to fasten upon *the* factor where in reality a combination of factors may be involved. Approached more broadly, the evidence is strong and fairly clear: such choice of food as the newer knowledge of nutrition teaches is unquestionably advantageous to the teeth.

There is also strong evidence that nutrition is not the only way in which food affects the teeth.

Hence, high intakes of protective foods and a low consumption of sugar are both important.

Boyd (1942) recommends the following daily diet for the normal child: "1 quart milk; 1 or 2 eggs; two 4-ounce servings of succulent, leafy, and root vegetables; two 4-ounce servings of fruit, one of which should be orange or other raw fresh fruit (tomato may be used as a substitute); one serving meat, fish, fowl, or liver; 1 teaspoon codliver oil; and supplementary foods such as potatoes, starches, bread and other cereal products, sweets and fats, in amounts sufficient to complete the caloric requirement for full activity."

The Forsyth Dental Clinic is reported as finding that caries incidence decreased 79 per cent in that part of its child population which followed a dietary of the sort just outlined, while among children of the same age and locality on unreformed diet it increased 13 per cent.

In 1952 the Food and Nutrition Board of the National Research Council published *A Survey of the Literature of Dental Caries* prepared after ten years' study by its Committee on Dental Health. This book reviews exhaustively both nutritional and non-nutritional factors which affect tooth development and decay, and should be

consulted by the student who wishes a more detailed treatment than has been given here. The following summarizing statements are quoted from this review:

Direct tooth-attacking factors

There is full agreement among investigators of dental caries that bacteria are necessary for production of dental caries . . .

Resistance to caries

Most investigators agree on the existence of resistance or degrees of susceptibility to dental caries, developed primarily during the formation and maturation of the tooth. One group of investigators claims that the resistance to caries is a *dynamic* operation as long as the tooth has a living pulp, implying vitality of the dental tissue . . .

It has been shown that several of the vitamins and many minerals, and a normal balance of the endocrine glands, are necessary for a biologically perfect tooth structure, but the nutrients responsible for optimum resistance to tooth decay are not known . . .

The marked reduction in dental caries in children during and after the second World War in war-torn countries seems to strengthen the view that a high caries rate may be reduced by substituting a major part of the high intake of sugar and other refined carbohydrates by less refined foods. Caries reduction by reducing sugar intake reported in other studies may also be interpreted in the same way. However, reduction of acid formation in one way or another without changing the diet has also proved to be beneficial . . .

Much valuable knowledge has been gained concerning the part played by saliva in maintaining dental health, but more work has to be done in this field. The importance of its buffering capacity, concentration of hydroxyapatite, and rate of flow are noteworthy. Also, there is still much to be learned about the influence of diet and the state of nutrition on the quality of saliva.

There is no doubt about the importance of nutrition in the development and maturation of teeth and its bearing on resistance to tooth decay, but to what extent nutrition plays a role during subsequent periods is controversial and needs clarification by further studies.

In spite of the many questions still open, we are inclined to share the optimistic view of McCollum that: "At any rate we now know how to produce good teeth as respects structure and how to preserve them in considerable measure from decay. We may confidently expect that further researches will within a few years see

complete unanimity of opinion as to the factors which operate to cause caries-susceptibility. Nutritional research has scored a great achievement in the field of dental science."

EXERCISE

After study of the available literature, including that later than the suggestions listed below, write a paper of from 200 to 500 words supplementary to the foregoing chapter.

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19

NUTRITIONAL CHARACTERISTICS OF FOOD COMMODITIES

Foods may properly be grouped in different ways according to the purposes in view. "The basic seven" was and is a useful device for giving emphasis to certain main types of foods; and guidance toward the choice of balanced diets by consumers who need not be versed in nutritive values. For fuller considerations, and especially such as involve the finding of common ground of understanding between nutritionists and agricultural economists, the most advantageous plan seems to be that of *classifying all foods into from ten to twelve groups*, taking account both of nutritional characteristics and of economic or commodity relationships, either in production or consumption or both.

Eleven food groups may well be: (1) the cereal grains and their products; (2) mature legumes and nuts; (3) potatoes and sweetpotatoes; (4) green and yellow vegetables; (5) citrus fruits and tomatoes; (6) other vegetables and fruits; (7) milk and its products other than butter; (8) meats, fish, and poultry; (9) eggs; (10) butter and other fats; (11) sugar and other sweets. A frequent modification of this is to treat eggs with meats, poultry, and fish, reducing the number of groups to ten. Less frequently, butter is treated as separate from other fats.

In terms of the agricultural economist, the grains, vegetables, and fruits are "primary" or "direct food crops" coming directly from the soil into human consumption; while milk, meat, poultry, and eggs are "secondarily derived" by the "processing" of crops through animals; and fats and sugars are in a third economic category because to so large an extent they are products of industrial technology as well as of agriculture.

In this chapter, we shall consider the nutritional characteristics,

place in the diet, and some of the commodity relationships of each of the eleven food groups just listed. The order of this listing affords, in our opinion, the clearest sequence in thinking of the place of each food group in the dietary when we assume that full use is made of each group in its turn as here arranged.

A governmental study of the distribution of the food expenditures of American families among these eleven food groups, and the contribution of each of these groups to the chief different factors of nutritive value of the total dietary or food supply, is shown in Table 29.

The student is advised to refer back to this table frequently in the following study of the nutritional characteristics and economy of each food group.

Grain Products

Cereal grains and their milling and bakery products are still the staff of life in the sense that this food-group contributes a larger proportion of nutriment to a larger part of the world's people than does any other.

As the late Sir Frederick Hopkins summarized the historic place of these foods in our diet: "Circumstances have to be very exceptional indeed when the growing of cereals does not yield an energy supply for the workers at less cost and with less relative effort than any other method of food production. Economic and social factors usually tend to make bread by far the most convenient form in which the cereals can reach the individual consumer. The nations of the West have acquired the habit of demanding a well-piled loaf, and for this the special properties of wheat gluten seem necessary. Hence the reliance on wheat in the West."

Stiebeling and Phipard (1939) found in their comprehensive study of American family food consumption that, "in all regions, and whatever the level of food expenditure, the largest share of the calories was derived from the grain products."

It was, of course, because flour and bread are consumed in such amounts by so large a majority of the people, that attention was attracted to this food group as a practicable means of improving broadly and promptly "the nutritional environment in which our people live," through the enrichment "program" or "movement."

Six cereal grains rice, wheat, corn (maize), oats, barley, and

TABLE 29. *Relative Cost and Contributions to Nutritive Value of Diet of 11 Food Groups: Urban Families in the United States, 1948* (Coons, 1950–51)

Food Group	*Percentage of total food cost*	*Percentage Contribution of Each Nutrient by Each Food Group*								
		Calories	*Protein*	*Calcium*	*Iron*	*Vitamin A value*	*Thiamine*	*Riboflavin*	*Niacin*	*Vitamin C*
Grain products	10.7	25.0	23.5	13.6	28.0	0.5	31.1	18.1	27.3	*
Dry beans, peas, nuts	1.4	2.6	3.9	1.6	6.9	0.1	3.8	1.5	5.1	*
Potatoes, sweetpotatoes	2.2	3.4	2.9	1.2	5.1	4.4	6.1	1.9	6.6	12.6
Leafy, green, and yellow vegetables	4.6	1.6	2.9	4.6	8.0	41.2	6.0	4.9	3.3	22.2
Citrus fruits, tomatoes	4.9	2.6	2.0	3.7	5.1	9.1	6.0	2.3	4.1	44.2
Other vegetables and fruits	8.3	4.2	2.0	3.6	7.4	6.9	4.7	3.8	4.1	15.0
Milk and its products other than butter	15.8	15.0	23.5	65.9	2.9	13.6	10.2	42.0	3.3	4.2
Meats, fish, poultry	27.4	13.9	29.4	2.1	24.6	8.4	25.1	16.9	43.8	1.2
Eggs	4.4	2.6	6.9	2.4	8.0	6.1	3.0	7.1	*	0
Butter, other fats, oils	9.2	17.3	2.0	0.6	1.7	9.7	3.4	0.8	1.7	0
Sugar and other sweets	4.9	11.8	1.0	0.7	2.3	*	*	0.4	0.4	0.6
Miscellaneous food accessories	6.2	no attempt to estimate nutrients								

* Less than 0.05 per cent.

rye are important in human nutrition. Their relative prominence is subject to wide geographic variation, partly due to climate and partly to differing preference of different peoples. When corn and oats are referred to as "feed" grains, it does not mean that they lack suitability for use as human food; but rather that (in the United States, at least) our normal crops of corn and oats so greatly exceed the amounts desired for human food that large quantities remain for animal feeding. In this country, the annual production of maize totals about 3 billion bushels, and of wheat and oats, about 1.3 billion bushels each; while rice, barley, and rye are of relatively little importance.

Outstanding characteristics of the grain products are: their acceptability and cheapness as sources of food calories and protein; and also (in their whole grain or enriched forms) as sources of iron, thiamine, and niacin. Nutritionally they need supplementation with calcium, vitamins A and C, and in riboflavin; and to make a diet fully satisfactory for growth, reproduction, or lactation the grain proteins may need moderate supplementation with some protein or proteins richer in lysine and tryptophan. In addition to its strictly nutritional characteristics, this food group aids the digestive process by conferring a favorable texture upon the food mass and its residue in the alimentary tract.

Present-day conditions therefore make it logical for nutrition-conscious people to consider anew whether we may not advocate a somewhat larger place for grain products in American dietaries than that to which they had sunk by about 1940.

During the year 1940–41 the National Research Council reestablished its Committee on Food and Nutrition (later renamed Food and Nutrition Board) and sponsored its collaboration with the Food and Drug Administration and the milling and baking industries. The resulting Enrichment Program has been fully recorded by R. M. Wilder and R. R. Williams in their bulletin entitled, *Enrichment of Flour and Bread: A History of the Movement,* published by the National Research Council.

Awakening realization of the nutritional desirability of enriching white bread led to studies of other enrichments as well as the one for which the name Enriched was officially authorized. Under the title, "What the Consumer Should Know About Bread," Professor C. M. McCay of Cornell reviewed in the *Journal of Home*

Economics of April 1949 several ways of increasing the nutritive value of bread by incorporating in the flour or dough such protein concentrates as soy flour, non-fat dry milk solids, dry yeast, wheat germ, corn germ, and dry whey. McCay concludes that bread is "a superb medium" for these special protein concentrates and that "the

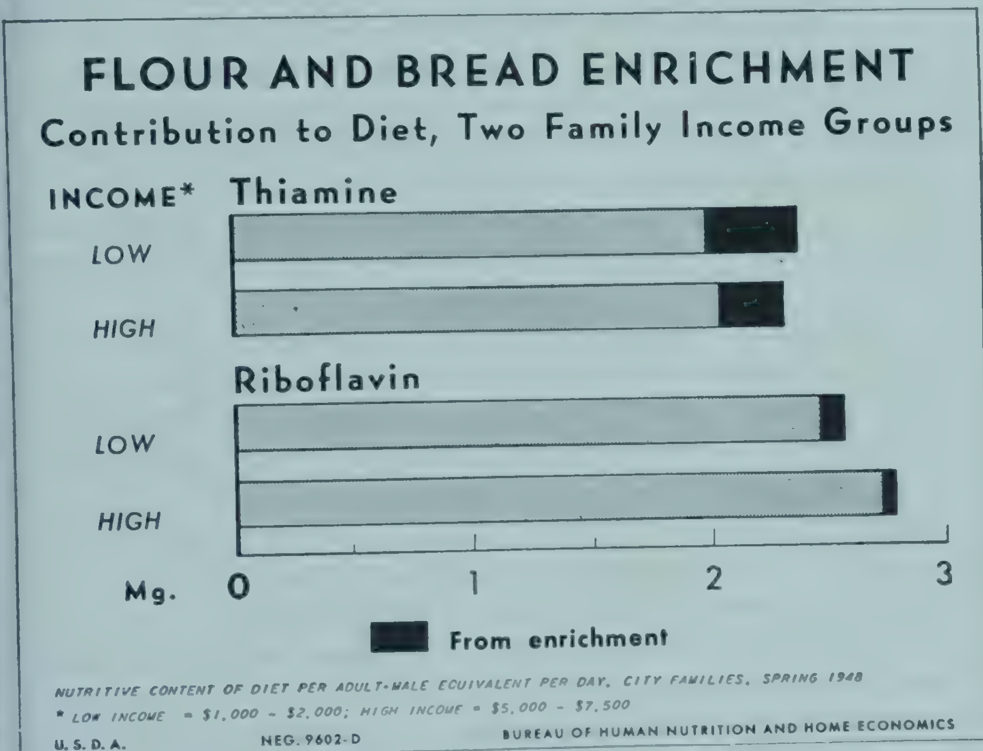

Fig. 30. Effects of enrichment on the thiamine and riboflavin intakes of typical low-income and high-income American families. Since the diets of low-income families give greater prominence to flour and bread (because of their cheapness) than do the diets of high-income families, these low-income families secure greater benefit from the Enrichment Program. (Courtesy of the U.S. Department of Agriculture.)

difference in cost between a very poor bread and one of very high nutritive value ranges only between one half and one cent per pound loaf."

For some years before the initiation of the movement for enriching flour and bread with thiamine, riboflavin, niacin, and iron there had been a general trend toward a wider and larger use of milk, and especially of skim-milk powder ("non-fat dry milk solids") in bread-making. Such addition of significant amounts of milk solids

obviously enriches the bread in its protein and calcium as well as some of its vitamin values. The process to which the term enrichment has been officially assigned is not a rival project but a further step. We should stimulate consumer demand for bread which has been enriched in both ways. According to Prouty and Cathcart a considerable proportion of the white bread made in the United States in recent years has contained enough of milk solids to double its earlier calcium content. Mineral salt mixtures used as "yeast food" in breadmaking also increase the calcium content of the resulting bread. Another means of enrichment of bread in vitamins of the B group is the use of specially grown yeast of extra high vitamin content. And always it is open to the consumer to demand bread from which less of the nutriment has been removed in the milling process, or to which the germ has been returned.

In the United States, wheat is by far the leading grain in the human diet; and it is estimated that 97 per cent of the wheat is used in highly milled "refined" forms. The enrichment of refined wheat products and other steps to improve the quality of white bread are therefore of prime importance in bettering the diets of the greatest number of people. Corn (maize), though grown in larger quantities than wheat, is much more largely used as animal feed, the human consumption averaging only about one-fifth that of wheat for the country as a whole. However, it is well known that certain groups of our population, especially in the South, give corn meal, grits, hominy and other maize products a very prominent place in the dietary. According to the 1948 U.S. Department of Agriculture food consumption survey, low-income families in Birmingham, Alabama, used 1.4 pounds of corn meal per person per week (as compared with 0.004 pound by families of comparable income in Minneapolis and St. Paul). The desirability of reenforcing the B-vitamin content of refined maize products in such regions is obvious. The Federal Food and Drug Administration set standards in 1947 for the enriching of corn meal and grits;[1] and a number of our Southern states have adopted legislation requiring the enrichment of maize products.

[1] Each pound of enriched corn meal or grits must contain not less than 2.0 nor more than 3.0 mgm. of thiamine; not less than 1.2 nor more than 1.8 mgm. of riboflavin; not less than 16 nor more than 24 mgm. of niacin; and not less than 13 nor more than 26 mgm. of iron.

It seems beyond doubt that this enrichment of maize products as well as that of wheat products, has played an important part in the markedly reduced incidence of reported cases of pellagra from 9,000 or more per year before 1942 to as low as 141 in 1951 (Wilder, 1952).

Though rice makes up an insignificant fraction of most American diets, so much of the world's population subsists mainly on this grain that techniques to improve the nutritional quality of milled (white) rice have enormous potential significance. One socalled "conversion" process retains a high proportion of the B-vitamins of brown rice, as illustrated by the following data (from Maynard and Nelson, 1951).

	Thiamine mgm./lb.	*Riboflavin mgm./lb.*	*Niacin mgm./lb.*
Rough brown rice	1.48	0.28	26.6
"Converted" milled rice	1.36	0.20	20.7
Raw milled rice	0.20	0.08	8.3

Mature Legumes and Nuts

Mature legumes and nuts are grouped together as direct food crops rich in proteins and thiamine. They are also excellent sources of iron and niacin. They doubtless deserve a larger place in our dietaries than we have yet learned to give them.

In their production, ordinary dry beans are much like a grain crop; and are, indeed, sometimes grouped with grains in agricultural discussion. They are, however, almost twice as rich in proteins as are the cereal grains. And soybeans (dry) are almost twice as rich in protein as are ordinary beans. The protein both of ordinary and of soy beans, needs cooking to make it readily digestible; and the nutritive value of bean protein has often been underrated because of feeding experiments in which it was fed raw. More recent research has shown that the protein of beans, when cooked as it is for human consumption, need not be discriminated against either on grounds of digestibility or of the nutritive value of the amino acid mixture which these proteins yield upon digestion.

Every food protein yields a somewhat different mixture of amino

acids—not so much different in kind as in the quantitative proportions in which the same kinds of amino acids are present. The one which is present in smallest amount, relative to the need of the person or animal being fed, is called the *limiting*[2] amino acid. This term may be used whether we are speaking of an individual protein or of the protein mixture contained in a food or a diet. Thus according to present-day knowledge, the "limiting" amino acid of beans is cystine-plus-methionine, while that of white flour appears to be lysine. Thus the proteins of beans and those of wheat flour have supplementary value to each other and the serving of Boston brown bread with baked beans is good nutritional practice. Hence also we see that it is entirely consistent to make baked beans (or a thick pea soup) the "main dish" of the largest meal on some days, while on other days or at other meals a different protein food may be chosen.

As more fully discussed in Chapter 6 (and as can be seen from Table 30), the proteins of ordinary beans, of soybeans, of peas, and of such nuts as have been sufficiently studied to permit a judgment (certainly of peanuts), all are sufficiently similar to those of meat that these foods can be used as nutritionally good alternatives[3] or substitutes for meat to a much larger extent than they yet are in the United States. Also these are all protein-rich crops which American farmers can readily produce more abundantly as rapidly as consumers will buy them. These facts were thoroughly studied from many viewpoints, especially during World War II, and may be emphasized with confidence.

Peanut butter spread on white bread tends to restore the protein, vitamin, and some of the mineral values of the whole wheat grain which are rejected in the milling process. It well deserves prominence in the diet, especially of growing children. The U.S. Department of Agriculture survey of 68 cities in 1948 found that only one-third of the households used peanut butter in the week under study.

The peanut, of course, is a legume comparable with peas, beans

[2] Because no one of the essential amino acids is apt to be entirely lacking from any natural food it is better to speak of the amino acid which is present in relatively smallest amount as the *limiting* amino acid, rather than to say that the food protein is "deficient" in it.

[3] *Alternatives* is the better word, but the continued use of the word *substitutes* is a true indication that a prejudice still exists.

TABLE 30. *Amino Acid Contents as Percentages of Total Protein** (Adapted from Block and Bolling, 1951)

	Arginine	*Histidine*	*Lysine*	*Tyrosine*	*Phenylalanine*	*Tryptophan*	*Cystine*	*Methionine*	*Threonine*	*Leucine*	*Isoleucine*	*Valine*
Foods of Animal Origin												
Animal muscle	7.7	3.3	10.0	4.0	5.0	1.4	1.2	3.2	5.0	8.0	6.0	5.5
Fish muscle	7.4	2.6	9.0	3.8	4.4	1.2	1.2	3.2	4.7	9.5	6.5	6.0
Liver	6.6	2.5	7.0	3.9	6.1	1.5	1.4	3.2	5.3	8.4	4.8	6.0
Eggs, whole	6.6	2.4	7.0	4.5	6.3	1.5	2.4	4.0	4.3	9.2	7.7	7.2
Milk, whole	4.2	2.6	8.7	6.0	5.5	1.5	1.0	3.2	4.7	11.0	7.5	7.0
Grains and Cereals												
Wheat, whole	4.3	2.1	2.7	4.0	5.1	1.2	1.8	2.5	3.3	7.0	4.0	4.3
white flour	3.9	2.2	1.9	3.8	5.5	0.8	1.9	2	2.7	7.0	4.2	4.1
Corn (Maize), whole	4.8	2.5	2.3	6.0	5.0	0.6	1.5	3.1	3.7	15.0	6.4	5.3
grits	3.1	1.6	0.8	6.7	6.4	0.7	1.1	2.5	4.1	15.0	6.4	5.3
Oats	6.8	2.3	3.6	4.5	5–6	1.3	1.8	2.0	3.6	8.0	4.9	5.4
White rice	7.2	1.7	3.2	5.7	5.0	1.3	1.3	3?	3.8	8.2	5.2	6.2
Legumes and Nuts												
Dried peas and beans	7.0	2.2	6.5	2.8	5.0	0.8	1.3	1.3	3.9	7.0	5.5	5.5
Peanuts	11.3	2.1	3.0	4.4	5.1	1.0	1.6	1.0	1.6	6.7	4.6	4.4
Soybeans	7.3	2.9	6.8	4.0	5.3	1.4	1.9	1.7	3.9	8.0	6.0	5.3
Other Vegetables												
Leaves	7.0	2.0	5.5	5.0	5–6	2.2	2.0	2.5	5.4	10	5	5
Potatoes	5.0	2.2	8.3		5.9	2.1		2.5	6.9	9.6	3.7	5.3
Yeast	4–5	3.0	7–8	3.6	4.5	1.3	1.1	2.0	5.5	7.5	6.0	5.8
Purified Proteins												
Casein	4.2	3.2	8.5	6.4	6.3	1.3	0.4	3.5	4.5	10.0	7.5	7.7
Gliadin	2.7	2.1	1.1	3.0	5.8	0.8	2.3	1.5	1.9	6.1	4.7?	2.4
Zein	1.8	1.7	0.0	5.2	6.4	0.1	1.0	2.3	3.0	23.7	7.3	3.0
Gelatin	8.2	0.9	5.0	0.5	2.3	0.0	0.1	0.8	1.9	3.5	1.7	2.8

* That is, grams of amino acid per 16 grams of nitrogen.

(including soybeans), and lentils. Most other nuts ("real" nuts as some fanciers say) are botanically fruits and agriculturally tree crops. The culture of nut trees and the consumption of nuts might well be increased.

Nuts are an alternative for meat toward which there is less of active prejudice than toward beans, but most of us still do not take nuts as seriously as they deserve, as one of the main protein-rich food groups. The well-deserved popularity of peanut-butter sandwiches might advantageously serve as an introduction to a much larger use of nuts in American dietaries. A generous dish of mixed nuts or of fruit-and-nut salad can well be the main dish of luncheon or dinner and an interesting and labor-saving way of diversifying the diet.

Thus there are good reasons, nutritional and economic, for giving increased emphasis to this food group in American dietaries. One can confidently expect that money thus spent will bring much more than its *pro rata* share of nutrients. If increasing acquaintance of consumers with these facts increases the consumer demand for beans, peas, soybean products, peanuts, and peanut butter, American agriculture can readily supply the increased demand with little if any increase of price. These are crops which are relatively easy to grow and to handle and which tend to increase the fertility of the soil because they "fix" nitrogen from the air in the form of compounds available to other plants as well as themselves. Careful investigations made during World War II showed clearly that only easy adjustments favorable to agriculture would be involved in meeting even a largely increased demand for the foods of the legume group.

Potatoes and Sweetpotatoes

These two foods are not closely related botanically which is the reason for making sweetpotato a single word. And to bracket them together may seem odd from the viewpoint of the fact that sweetpotatoes are an important source of vitamin A value while (ordinary) potatoes are not. But from the viewpoint both of agricultural production and household use, they are sufficiently of the nature of alternatives (as foods chiefly grown for their calorie values, and characterized by high carbohydrate content) to warrant their being

bracketed as one of the 10 to 12 groups into which we find it helpful to classify all of our important foods.

If a single term were being chosen to characterize this food group, it would probably be *starchy*. In this respect they are like the grains, and some students of food-supply problems count together the starchy seeds, roots, and tubers as foods of relatively low "protective" value on which the peoples of some areas are forced largely to live, and from which, when economically able, they tend to shift toward diets higher in protein and fat, and perhaps more diversified in other respects also.

But potatoes and sweetpotatoes are not such "one-sided" foods as most people probably suppose them to be. In the average of the presumably representative American family dietaries summarized in Table 29, it may be seen that an investment of 2.2 per cent of the food money in this food group brought a return of 3.4 per cent of the calories; 2.9 per cent of the protein; 1.2 per cent of the calcium; 5.1 per cent of the iron; 4.4 per cent of the vitamin A value; 6.4 per cent of the thiamine; 1.9 per cent of the riboflavin; 6.6 per cent of the niacin; and 12.6 per cent of the vitamin C. Thus the investment in this food group brought a return which was not only large in proportion to its cost but also fairly well distributed over the different main factors in the nutritive value of the diet. And even the calorie-conscious need not neglect this food group since it brings five out of the eight listed nutrients in proportions exceeding its calorie value.

As noted in Chapter 6, the proteins of potatoes, while low in percentage, are excellent in nutritional quality, and compare favorably with "animal" proteins as sources of lysine and tryptophan, in which the cereal grains are relatively low.

Despite the merits of potatoes and sweetpotatoes as an economical source of fairly well-rounded nourishment, the per capita consumption has decreased from over 200 pounds per year in 1910, to 165 in 1925, 130 in 1940, and 103 pounds in 1952.

Green and Yellow Vegetables

Green and yellow vegetables are grouped together because of their relatively high vitamin A values. We say "values" rather than "contents" because, as previously explained, these foods contain

not vitamin A itself but precursors (or provitamins A)—notably carotenes—which the body transforms into vitamin A and then uses in the same manner as if it had received the vitamin A directly from the food itself. The fact that the chief precursors are named carotenes for the carrot makes it easy to remember that high vitamin A value is characteristic of most yellow as well as all green vegetables. In the latter, however, the yellow color is hidden by the presence of the intensely green chlorophyll.

The economy of this food group compared with others, as sources of vitamin A, is illustrated in Table 29. In the American dietaries there summarized, the expenditure for green and yellow vegetables was only 4.6 per cent of the total food expenditure, yet it brought 41.2 per cent of the total vitamin A value. This group also supplied 4.6 per cent of the calcium, 8.0 per cent of the iron, 6.0 per cent of the thiamine, 4.9 per cent of the riboflavin, 3.3 per cent of the niacin, and 22.2 per cent of the vitamin C. As we saw in Chapter 15 that liberal intake of vitamin A is very beneficial to health and longevity, a food group so rich in vitamin A value and which also contributes important amounts of several other factors of nutritive value, is one which might well be promoted to a larger place in our dietaries. Experts of the U.S. Department of Agriculture have recommended that production and consumption of this food group be increased promptly by 15 to 20 per cent which, they report, would be a very practicable adjustment which the growers of these foods could easily make just as rapidly as there is prospect of sufficient consumer demand.

Actually, the use of this food group, after rising from a per capita average of 63 pounds per year in 1910, to 95 pounds in 1925, and 131 pounds in the peak year of 1945, has since then fallen back to about 103 pounds per person per year; and the national dietary supply of vitamin A value and ascorbic acid has fallen with it.

Early in the era of the newer knowledge of nutrition McCollum emphasized the efficiency of green leaves in supplementing seeds and their products in the dietary; and attributed this to the relative richness of the green leaf foods in both calcium and vitamin A value. Quinn and coworkers showed that vitamin A value accompanies greenness not only in leaves but also in green peppers and green beans. The green and yellow vegetables are quite varied

both botanically (as to the kind and the organ of the plant) and in nutritional character. Illustrations are as follows:

Beans, green snap or string, succulent green pods with immature seeds, have shown about 600 International Units of vitamin A value per 100 grams. This is a value worth taking into account, though much below those of typical dark green leaves. *Broccoli* comprises flower buds together with accompanying twigs and leaves. This total edible portion has shown 3000 to 7000 International Units per 100 grams. If, as is sometimes done, the leaves are rejected, about two-thirds of the vitamin A value is thereby lost; the other third is in the flower buds, the twigs having only traces. The leaves are also richer than either the flower buds or the twigs in riboflavin and calcium, while the flower buds are richest in phosphorus. Broccoli is easily grown in home gardens, and is now also a fairly staple market commodity. The plant branches freely and not only does each branch produce a head or spray of flower buds but when these are plucked at the succulent stage successive crops are borne through a long season. *Cabbage* varies from a loose bunch of green leaves of good calcium and vitamin A and C value to a tight head, most of which is nearly colorless and of but little vitamin A or calcium value, which however contains a worthwhile amount of vitamin C. *Carrots* contain carotene not masked by chlorophyll so the intensity of the characteristic color is roughly proportionate to the vitamin A value. This has been reported as from 2000 to 12,000 International Units per 100 grams, increasing with the growth of the carrot. *Collards* are an important vegetable in the Southern states; but as yet (1956) are not much brought to the Northern markets. They might be described as something between green cabbage and kale. *Kale* is a deep-green leaf food which is hardy, and rapidly replaces the leaves harvested from it so that it is available fresh throughout the entire year. Its vitamin A value, and its vitamin C and calcium contents, are all high. Its nutritive values are outstanding and deserve to make it the green leaf food of choice. Its superiority to spinach has been explained in Chapter 8. Its vitamin A value is of the order of 7,000 to 20,000 International Units per 100 grams. *Turnip greens* are comparable with kale. *Watercress* consists too largely of stem to equal kale and turnip greens, but is very pleasant to eat raw and can be a worthwhile source of calcium,

vitamins A and C, and riboflavin. In the famous experiments (described below) of Dr. H. C. C. Mann in which various foods were tried as supplements to the diet of a boys' school, milk stood first and watercress second in outcome.

Citrus Fruits and Tomatoes

Citrus fruits and tomatoes are likely to retain the high esteem they now enjoy as rich and reliable sources of vitamin C, even though we are learning that potatoes, sweetpotatoes, and leaf vegetables can readily be so handled as also to constitute important sources of this vitamin. This is true because we now have good evidence that we derive added benefit from increased intake of vitamin C up to several times the amount which is needed to protect from manifest scurvy. Also these foods are now such well established staples that there is little danger of disturbingly large fluctuations in market supplies or in cost to consumers. Except for the war years when it rose as high as 133 pounds, the annual consumption of this food group has been fairly well stabilized at about 110 pounds per capita for nearly two decades. The development of the frozen concentrated citrus fruit juice industry has progressed phenomenally in the past few years until now more oranges are consumed in this form than fresh, except perhaps at the height of the fresh orange season.

Other Fruits and Vegetables

Other fruits and vegetables, while not such outstanding sources of individual nutrients, are good all-around contributors to the mineral content and vitamin values as well as to commendable diversification of diet. They also contribute to the body's good intestinal hygiene, and its alkaline reserve for the insurance of neutrality of body fluids and tissues.

Liberal use of a wide range of these other fruits and vegetables usually makes the dietary as a whole both more palatable and nutritionally better balanced than the American average. We are also advised that a larger consumer demand for these other fruits and vegetables tends to a better balanced agriculture.

When each of the six food groups of the preceding paragraphs

is studied (preferably in the sequence suggested at the beginning of this chapter) from the point of view of making full use of what it offers, probably each student will find good reasons for giving each of these six food groups a somewhat larger place in the diet than it is at present generally given in American dietaries. This is partly because our American food habits have hitherto been more or less tradition-bound and partly because today's newer knowledge of nutrition affords us much clearer and fuller guidance to good use of food resources than has ever been available before. And one who now plans a food budget in this way will probably be surprised to find in what a large degree nutritional needs can advantageously be met from the six food groups which are economically the "direct food crops." Very probably the only nutritional factors seeming to need further attention will be animal protein (vitamin B_{12}?), calcium, and riboflavin; and of all of these milk is an outstanding source. This is also true of all the staple products of milk except butter.

Milk

Milk (*with its products other than butter*) thus becomes the logical seventh food group of the present classification. It stands in a class by itself in the economy and efficiency with which it makes good such low points as may remain when present-day knowledge has been applied to the problem of making full use of the foods of the six preceding groups. For the past forty years the science of nutrition has emphasized in its non-technical teaching, the saying that: "The dietary should be built around bread and milk." This teaching has shown beneficial results in an increased per capita consumption of milk, while at the same time the more recent research has shown still stronger scientific support for such emphasis as in the supplementary relations of milk proteins to those of grains and other seeds, the benefits of liberal amounts of food calcium, and the discovery of the existence and nutritional importance of riboflavin, of which (as of calcium) milk is the largest supplier in typical American dietaries.

According to the official estimates of the U.S. Department of Agriculture, the total annual supply of milk in the United States in 1952 was 115 billion pounds. Of this, it was estimated that 53 per cent was consumed as fluid milk and cream, while 40 per cent was used

for the factory production of dairy products. Table 31 summarizes the per capita consumption of various dairy products in the prewar year of 1939, in the peak consumption year of 1945, and in 1952.

Translating the other dairy products into the quantities of milk to which they correspond, it was estimated that in 1952 the "fluid milk equivalent" of the per capita consumption of dairy products amounted to 249 quarts a year. Nutritionally it makes little difference whether milk is consumed as such or in such forms as canned or dried milk, ice cream, and cheese. But buttermaking is apt to

TABLE 31. *Annual per Capita Consumption of Various Dairy Products* (from *Agricultural Statistics, 1953*)

	Fluid milk, cream pounds	*Butter pounds*	*Cheese* pounds*	*Condensed, evaporated pounds*	*Ice cream pounds*	*Dry whole milk pounds*	*Dry skim milk pounds*
1939	332	17.2	5.8	17.6	10.8	0.13	2.1
1945	399	10.8	6.6	18.0	15.4	0.37	1.9
1952	352	8.7	7.7	17.4	17.5	0.42	4.4

* Does not include cottage cheese.

involve a large loss to human nutrition of the skimmed milk from butter manufacture. Gradually, however, dried skimmed milk is being brought more fully into human consumption. There should be no interference between a growing use of fresh milk and cream on the one hand and, on the other, milk products other than butter.

With some fluctuations from year to year, the per capita production and consumption of milk in the United States increased for a generation up to 1945–46, since when it has diminished somewhat. With growing knowledge of the nutritional importance of liberal consumption of milk as such or in the form of its staple products other than butter, it may be hoped the rise will be resumed.

Dr. H. C. Corry Mann's experiment of 1922–26 with English school boys, is of great interest and significance. Its problem was: whether a typical English dietary, which had been planned and adopted "with every consideration for the welfare of those to be nourished by it" would be improved by increasing the proportion

of what were beginning to be called "protective foods"—milk and green leaf vegetables—and, if so, to what nutrient factor would the improvement be due?

That is, starting from a baseline dietary which was "medically adjudged" to be adequate according to the nutritional knowledge of 1922, could improved results in human nutrition be obtained by simple supplementary feeding guided by the "newer knowledge" then beginning to be suggested by nutritional research?

The subjects of this investigation were English boys living in a village-type boarding school 11 miles from London where 500 to 600 boys between 7 and 11 years of age lived continuously, each boy for 11 to 12 months each year. This school-village comprised 19 cottages and a central dining hall. Each cottage housed about 30 boys. And the boys of each house had their own dining table.

Boys of House No. 1 received the regular diet of the school and served as the direct control group for each of the seven other groups as follows: Each boy of House No. 2 received the regular diet plus a supplement of 1 pint of extra milk a day (388 Calories); those of House No. 3 received essentially the same number of supplementary Calories (350 a day) of sugar; those of House No. 4 received 387 Calories of supplementary butter a day; those of Houses No. 5 and No. 6 each received a supplement of ½ to ¾ ounce of watercress daily; those of House No. 7 received a daily supplement of casein, equal to the amount of protein in the pint of extra milk which was fed to each boy of House No. 2; and those of House No. 8 each received daily 379 Calories of vegetable margarine (vitamin-free fat) a day. With all other conditions very carefully held uniform, the boys receiving the supplement of extra milk did best; and those receiving the watercress, second best.

The discussion in the official report of the experiment is centered mainly upon the effects of the supplementary milk as shown by comparison of the boys receiving it with those of the control group (House No. 1) as well as with the boys in the school as a whole.

The boys receiving the supplement of extra milk made very significantly better gains both in height and weight, and in "fitness" and "spirit."

As the results from Houses No. 3, 4, 7, and 8 indicated that the benefit from the milk supplement could not be attributed to carbohydrate, fat, fat-soluble vitamin, or protein, the investigators concluded that the clearly demonstrated superiority of the milk supple-

ment must have been due to "something more specific to the milk." In terms of known nutrients, and in view of the fact that the second best records were made by the boys receiving watercress, the "specific" factor may well have been the combined increments of calcium and riboflavin.

The advantage of increasing the proportion of milk, even in an already adequate diet has also been very conclusively shown in experiments continued throughout entire lives and successive generations of suitable animals of relatively short natural life cycle.

Using rats as experimental animals, the nutrition laboratory of the Columbia University department of chemistry studied the effects of different quantitative proportions of wheat and milk in dietaries which, for the sake of certainty of interpretation, were simplified to consist of these two foods with table salt and distilled water. It was found that five-sixths ground whole wheat with one-sixth dried whole milk (Diet A) made an *adequate* food supply, but that a mixture of two-thirds ground wheat and one-third dried milk (Diet B) was *better*. Compared with those on Diet A, the animals on Diet B showed more rapid and efficient growth and development (corresponding to the freshmen entering college taller yet younger), higher adult vitality, and a longer prime of life. While general attention was attracted by the fact that the adult life expectation or "life cycle" was extended by about ten per cent, it is chiefly worthy of emphasis here that undoubtedly the "health as a positive quality of life" was higher at every age.

In terms of the set-up of the original experiment, the variable factor in the dietary was the quantitative relation of its two major ingredients: wheat, taken as typical of foods furnishing energy at low cost; and milk, as representative of the "protective" foods needed to "balance" the dietary.

Greater prominence of milk in the food supply of the individual, the family, or the nation means enrichment of the diet in its calcium content, and practically always in its riboflavin content and vitamin A value also. And these are among the nutritional factors which we know to possess large areas of beneficial increase above the level of mere adequacy. Thus milk is the food most likely to be effective in meeting the actual need of a deficient diet; and also when the diet is already adequate, milk is the food most likely to be effective in building to higher levels of positive health.

Because, for Americans and Europeans at least, the calcium intake depends chiefly (Fig. 31) upon the consumption of milk in some form (including cheese, cream, and ice cream), and because calcium is probably more often deficient in the dietary than any other element, and certainly falls below *optimal* amount in many present-day dietaries, the explanation of the importance of a liberal use of milk tends to be given largely in terms of calcium. That milk is a highly evolved vehicle for meeting the calcium need in nutri-

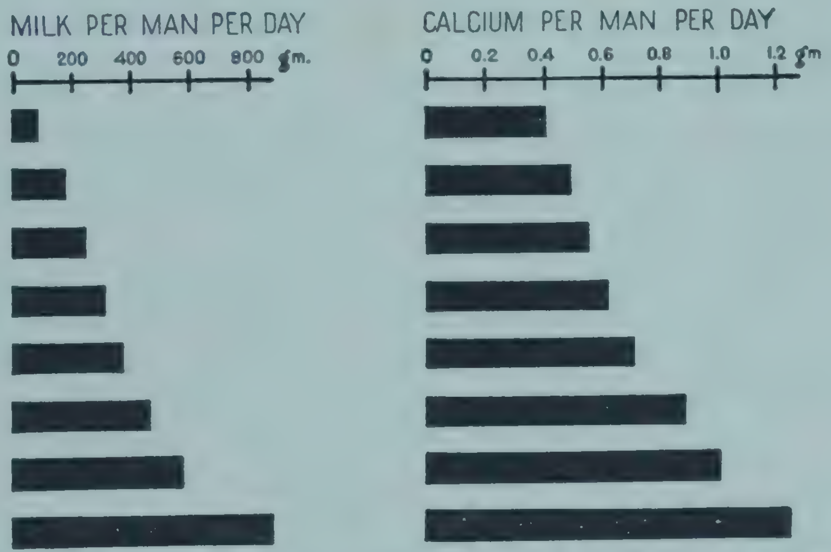

Fig. 31. The relation of milk consumption to the calcium content of the dietary. Here the 224 American dietaries previously mentioned were arranged in order of milk consumed and their calcium contents averaged in eight groups of 28 dietaries each.

tion is further illustrated by the fact that its other constituents are such as to enable it to convey calcium with outstanding efficiency, a quart of milk actually containing more calcium than does a quart of limewater (saturated solution of calcium hydroxide).

And it must never be supposed that the calcium tells the whole story. For milk contains all the factors known to be needed in the nutrition of the mammalian species, and in view of the experiments of Osborne and Mendel it doubtless contains also any such essential factors as may be still awaiting discovery. As the late Dr. Mendel emphasized, while milk does not contain all the vitamins in as high a proportion as we want them, it is probable that milk contains a

larger number of the vitamins in reasonably well balanced proportion than does any other one food.

Milk is the one article whose sole function in nature is to serve as food, and the one food for which there is no fully satisfactory substitute. Mrs. Mary S. Rose wrote: "No other food can so well serve as the foundation of an adequate diet, because no other reinforces (the diet) at so many points." And again, "Milk is particularly adapted to offset the total lack of minerals in fats and sugars, and the serious mineral deficiencies of white flour, hominy, polished rice, and other refined cereal products so widely used in American dietaries."

The milk of different species differs somewhat, and some methods of preserving milk may diminish its vitamin C and, perhaps, its thiamine content; but all the generally recognized commercial forms of milk resemble each other much more closely than does any other food approach milk in nutritional characteristics.

In addition to the outstandingly efficacious amino acid make-up of its natural mixture of casein and lactalbumin (discussed in Chapter 6 and also evident from Table 30), milk has other nutritional characteristics which in the long course of mammalian evolution have become fixed, doubtless because of their "survival value" in the promotion of growth and development, health and efficiency.

Its uniquely rich content of highly dispersed and thus readily assimilable calcium has already been noted. This makes it the most advantageous food source of calcium for the high calcium needs of the body which are fairly obvious during the period of the growth and development of the skeletal system; and, while less generally recognized, are important also to adult vitality and "the preservation of the characteristics of youth." Phosphorus also is contained in milk in readily assimilable forms and in an amount which makes milk an important source of phosphorus of good calcium: phosphorus ratio. The iron and copper contents of milk are low, but correspondingly the baby is born with reserve stores of iron and copper in the body, largely in the liver.

While subnormal levels of vitamins in milk have been produced experimentally, the rations used to induce them are such as are known, if long used, to diminish the productivity of the cow, so that dairy farmers have no desire to use them. Hence in practice few cows are so fed, and those that are do not yield enough milk

to have much influence on the quality of the market supply. The modern farmer feeds his milch cows vitamin-rich rations the year round. Thus milks of subnormal vitamin value are less common in the market, and commercial winter milk is more like summer milk, than the scientific literature might lead one to expect.

Meats, Fish, and Poultry

In view of the high dietary place given to meat by most people who can afford it, one who seeks thoroughly to assess the basis and wisdom of the traditional and economic place of meat in American

TABLE 32. *Consumption of Milk (Equivalent) Compared with Consumption of Meat, Poultry, and Fish: Families with Children, Grouped According to Relative Per Capita Consumption of Milk**

	Milk equivalent, % of average	*Meat, fish, and poultry, % of average*
Group 1	56	117
Group 2	80	105
Group 3	99	99
Group 4	120	96
Group 5	148	84

* Data adapted from U.S. Department of Agriculture, *Agriculture Information Bulletin No. 132.*

and European food supplies cannot but be strongly impressed by the lack of comprehensive studies carried out by the newer methods of nutritional research. Studies at Columbia in which meat was added to the basal Diet A or 16 (elsewhere described as consisting of five-sixths whole wheat and one-sixth dried whole milk) indicated that increasing the protein content in this way, which had the effect of still further diluting the calcium which was already in minimum-adequate supply, presented potential hazards to some individuals at some stages of the life cycle. As explained in Chapter 8, the non-beneficial effects suggested a calcium-protein imbalance, and were in fact largely obviated by the inclusion of extra calcium in the meat-supplemented diets. Such findings suggest the desirability of extra emphasis on a generous calcium intake by individuals

who are inclined toward heavy meat consumption— which would seem to include a large proportion of Americans in comfortable economic circumstances. In actual American practice, there appears to be a tendency for meat and milk to compete with one another for the consumer's food dollar; so that those families whose use of milk is low and who therefore have lower-than-average calcium intakes are the very ones who tend to make the most liberal use of meat. This is illustrated by the data of Table 32. Here, families were grouped into five classes according to the consumption of milk (equivalent) per person, and the consumption of various foods averaged within each of the five groups. For ease of comparison, the values for each food group are expressed as percentages of the per capita average of the entire sample, i.e., of all five groups.

Official statistics of per capita consumption of foods of the meat group in 1952 are as follows:

Food	*Pounds*
Beef	61.3
Veal	7.1
Lamb and mutton	4.1
Pork	71.6
Fish*	10.8
Chicken	29.6
Turkey	5.4

* Figure for fish is 1947 estimate.

Here the total meat—in the sense of beef and veal, lamb and mutton, and pork (excluding very fat cuts such as bacon)—was 144.1 pounds for the year; the total of these meats plus fish, 154.9 pounds; and of meats, fish, and poultry, 189.9 pounds. In general these statistics show that the high levels of consumption of meats reached in the United States in wartime were being maintained several years after the war.

Studies made by the U.S. Department of Agriculture in 1948–49 indicate that in the average family budgets of urban communities about one-third of all income goes for food; and that of this about one-fourth is spent for meat—24 per cent of the food money, to be exact—with an additional 10 per cent for fish, poultry, and eggs. "The part of the food dollar spent for meat was about the same at

all income levels, but the part of the income spent for food varied widely with income—from 74 per cent for families of less than $1000 income to 17 per cent for families with incomes of $7500 and over."

Low-income families ate more meat, both absolutely and relatively, in 1948 than in 1942, while higher-income families ate about the same amounts of meat in these two years. This closer approach of the low-income people to the food habits of their higher-income fellow-citizens is probably more significant psychologically than physiologically, for even the 1942 low-income consumption of protein was already liberal, and the traditional bias toward high consumption of "animal protein" has lost its once supposed nutritional basis with the discovery of vitamin B_{12}; which is as much a bacterial as an animal product, and is not protein.

When grain products, vegetables, fruits, and milk have all been given their full places in the diet, the result is a food supply and dietary of such excellence that the extent to which meats, fats, and sweets are added is of relatively little consequence in normal nutrition. The appeal which meats, fats, and sweets make to the palate and the sense of satiety is enough more than amply strong in most people so that those of us who enjoy relatively comfortable purchasing power may well think in terms of moderating our consumer demand for these three types of food; in the interest of more equitable distribution. This can be physiologically and psychologically better for all concerned, through avoidance of overweight and enhancement of a sense of social justice.

This last has (too often in the past) been "shrugged off" with the implication that dietaries differ as a matter of racial or social custom. Now that the importance of nutrition is more widely and keenly appreciated there is need for more frankness in facing the problem how far dietary differences are truly due to different social *choices* and how far they are forced by economic disparities. And in this connection we need fuller knowledge as to long term effects of differing levels of consumption of different foods.

Tressler, Birdseye, and Murray (1932) found that the tenderizing of quick-frozen meat continues during cold storage. Tenderness of beef as it comes to cooking need not, therefore, involve the inherently expensive grain feeding of the meat animals. Much more economically may these be slaughtered as they come from good

pastures and the meat allowed to attain added tenderness while waiting in the commercial or family refrigerator.

As may be seen from Table 30, the proteins of meat are somewhat similar to those of milk and of eggs in their amino acid make-up, and therefore in the efficiency with which they supplement the proteins of bread and cereals.

The different lean meats that have been studied are about equally good sources of riboflavin and apparently also of niacin, while in thiamine pork is much richer than beef.

On the other hand, meats contain relatively little of calcium, of vitamin A, or of vitamin C, so that in these respects they do not serve (as does a combination of milk and fruit) to make good the nutritional shortcomings of the breadstuffs and cereals.

The foregoing statements are made with muscle meats chiefly in mind, since the glandular organs can, in the nature of the case, constitute but a small fraction of the general meat supply. So far as it goes, liver (while varying depending on how the animal was fed) is apt to contain, weight for weight, much more vitamin A and vitamin C than muscle meats (as well as more of riboflavin, niacin, and vitamin B_{12}).

Eggs

We do not know the origin of the folk-lore verse to which Hutchinson gave currency, characterizing eggs as:

> Treasure houses wherein lie,
> Locked by Nature's alchemy,
> Flesh, and blood, and brain, and bone.

As rich sources of some nutrients of which we do not always get enough, eggs well deserve inclusion among the "protective" foods. But they do not (like fruits, vegetables, and milk) tend to safeguard the hygiene of the intestine and the reserve alkalinity of the blood and tissues; and for these and other reasons some careful students of nutrition have tended to keep the egg in about its old accustomed quantitative place in the typical American dietary, namely, 4 to 6 eggs per capita a week; while giving a growing place to fruits, vegetables, and milk. Some, however, have recommended increasing egg consumption to an average of at least an egg a day per capita.

Actually, the average egg consumption in this country has increased even more: from an average of 4 to 6 eggs per week in the 1930's to about 8 eggs per week in 1952. In view of this increased prominence of eggs in our national dietary, it would seem especially desirable to get further long-run experimental evidence as to the nutritional effects of such a shift. Much of value might be learned from full-life, successive-generation experiments with dietaries containing different liberal allowances of eggs, fed to laboratory animals whose nutritional chemistry (in respect to the factors of which eggs are important sources) is similar to our own.

In some respects eggs may be regarded as standing midway between meat and milk in nutritional characteristics. Like meats, they have been considerably studied as to particular points; but still need more comprehensive investigation by feeding at different levels throughout entire life cycles of successive generations. Egg protein resembles meat and milk protein in nutritional efficiency, and egg fat is easily digested because of its emulsified form. The mineral contents of eggs are much like those of lean meats.

Eggs are unique among staple foods in their relatively high vitamin D value (though of course a very small amount of a fish liver oil may contain as much vitamin D as does a whole egg). Eggs are also an important dietary source of vitamin A, thiamine, riboflavin, and probably other members of the B group of vitamins. The vitamin C content of eggs is negligible.

Fats and Oils

The problem of the proper place of commercial fats in the food supply presents several complications. For one thing, the demand for fat is (quantitatively speaking) largely a matter of national habit. During 1914–18 when a concerted effort was being made to ensure adequate food supplies to all the Allied peoples, it was found that a much higher per capita supply of fat was needed for efficiency and morale in the Occidental than in the Oriental countries. For the civilians as well as the soldiers of the European peoples, it was deemed important to provide at least 70 grams (two and one-half ounces) of fat per capita per day, while the Oriental peoples felt no need of so much.

People of the Western World want liberal use of fats in cookery

to give their foods the flavors, and perhaps even more particularly the textures, to which they have accustomed themselves; and also "fat sticks to the ribs" in the sense that a meal of a given calorie value does not so quickly leave the stomach if a liberal percentage of its calories is in the form of fat. And so, of course, the longer each meal stays in the stomach, the less likely is it that the muscular signals from an empty stomach ("the pangs of hunger") will be felt before the next meal.

The problem of specifically essential fatty acids has been discussed in Chapter 2. Though some fat is necessary as a source of essential fatty acids, and though butter and fortified margarine have some importance as sources of vitamin A, the group of commercial fats as a whole represents one-sided nourishment and the large use made of these foods in typical American dietaries represents dilution of the diet as a whole with calories which bring little else of nutritional value. On this score alone, some reduction in our use of commercial fats would seem wise. Of recent years a more serious charge than mere dietary dilution with "empty calories" has been directed at our high national consumption of food fats: that this practice is somehow correlated with the high incidence of arteriosclerosis and other vascular disorders in this country. Though various aspects of the problem are still controversial, the apparent association of these two factors, whether directly causative or not, seems sufficient grounds for restricting somewhat our use of this food group.

Sugars and Other Commercial Sweets

In nature the sweetness of the nectar of a flower is quite clearly a bait to secure the visit of the bee and the distribution of the pollen by his agency. The sweetness of the flesh of a fruit guides animals to consume something that contains not only sugar but also significant amounts of mineral elements and vitamins; and in baiting the animal to eat the fruit it also serves the plant by securing distribution of its seeds.

The biological utility of artificially refined sugar is much more circumscribed. Nutritionally it is the extreme case of a one-sided food; for it furnishes calories and nothing else.

The repeated research findings of Bunting and others, that increased prominence of sugar in the dietary means increasing proportion of tooth defects in children, should not be ignored.

It is probably true for the people as a whole, as was said in a discussion of the problem of sweets for children (published as a leaflet by the American Child Health Association and reprinted by the American Public Health Association in a report of its Committee on Nutritional Problems), "that in general the proper place of sugar in the food supplies and eating habits . . . is not in such concentrated forms as candy, nor in the indiscriminate and excessive sweetening of all kinds of foods, but rather as a preservative and flavor to facilitate the introduction into the . . . dietary of larger amounts of the fruit and the milk, the importance of which to . . . health has been increasingly emphasized with each year's progress in our knowledge of nutrition."

Within a relatively short time (from about 1825 to about 1925) as we saw in Chapter 2 sugar consumption has grown from about 10 pounds to about 100 pounds per capita per year in the United States,[4] so that now most families take over a tenth, and many take probably as much as a fifth, of their total food calories in the form of sugar which furnishes practically no protein, mineral element, or vitamin. Obviously this must have the nutritional result of lowering the intakes of protein and of the mineral elements and vitamins by one-tenth to one-fifth from the levels at which they would otherwise be consumed. Is this desirable?

EXERCISES

1. Answer the question with which the above text ends, and explain your answer in from 500 to 1000 words.

2. How do recent advances of knowledge of the differences between the merely adequate and the optimal levels of intake affect your judgment as to the use of so much "refined" food as was common in the first third of the twentieth century?

3. Write a summary of suggested means of improving the nutritive quality of bread. See which of these improved breads have found their way to your local market.

[4] It dropped as low as 73 pounds per capita (for civilians) during World War II, but reverted promptly after the war to prewar levels.

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20

FOOD COSTS AND VALUES: NUTRITIONAL GUIDANCE IN FOOD ECONOMICS

We have seen that, as Lord Astor put it, the newer scientific knowledge of nutrition makes the practical problem of food supply a question "not only of enough food, but enough of the *right kinds* of food."

And individual, family, and community food supplies doubtless have been, and still are, responsible for many of the relatively low levels of accomplishment for which in lack of this new knowledge an undue share of blame has in the past been laid upon heredity. However, it was estimated in the U.S. Department of Agriculture Yearbook for 1939, that probably 99 per cent of the people born in this country have heredity good enough to enable them to become productive workers and excellent citizens, but that half of them "do not get enough in the way of dairy products, fruits, and vegetables to enable them" to enjoy the full measure of health and vigor which is potential in their hereditary birthright. In the years since that estimate, the consumption of fruits, vegetables, and milk by low-income families has increased, but a further increase is both desirable and practicable.

The Economic Setting of the Problem of the Best Use of Foods

In the choice of one's food, or in purchasing the food for a family or other group, one usually must observe an economic limitation. This fact has been implicitly recognized in the foregoing Chapters and accompanying Exercises. The present Chapter undertakes a

somewhat more explicitly economic approach. Also, whereas previous Chapters have been written primarily in terms of the individual consumer, this one is chiefly in terms of the family food budget: partly because the majority of readers will presumably spend most of their lives as members of family groups; and partly because in studies and writings on food economics the family is so frequently considered as the consuming unit. To comply with custom in this respect involves no failure of appreciation of the fact that in another aspect the food as it enters the home is still a raw material for processing by the homemaker.

Detailed advice upon the budgeting of incomes would lead beyond the scope of this book. It is, however, part of the function of this Chapter to emphasize the fundamentally important fact that science now finds it possible to do more for health, efficiency, and welfare through nutrition than was previously supposed or even seriously imagined; so that, with nutrition carrying a larger share of the responsibility for making life worth while, it is logical that an increased share of the cost of living should be budgeted for the cost of food.

And even under difficult economic conditions it is possible for this to be done, now that nutritional science furnishes clearer guidance to the better use of food. Statistics show that such lines of expenditure as adornment (other than clothing) and amusement (other than by means of food, clothing, housing, and the automobile) run to very significant proportions even at the lower income levels. Hence the improvement of food economics under the guidance of the science of nutrition may be two-fold: (1) a better distribution of the food money; and (2) often also the allotment to food of a somewhat higher proportion of the total income, or of the total budget for the cost of living. And such a suggestion is not a proposal to diminish the few pleasures of the poor. Rather, it helps them to gain their greatest satisfactions.

For the satisfaction derived from such higher accomplishment as is made possible by higher health and efficiency exceeds the pleasure of mere consumption of goods; and in most families it is in turn exceeded by the contemplation of still higher health, efficiency, and accomplishment in and by the children who get the benefit of the newer knowledge of nutrition more completely and from an earlier age than did their parents.

Whatever the income, then, much depends upon the individual consumer's choice and use of food.

United States Food Consumption Surveys of 1948–1949

During 1948 and 1949 the U.S. Department of Agriculture conducted a nationwide survey of family food consumption and expenditures in some seventy cities throughout the country, with

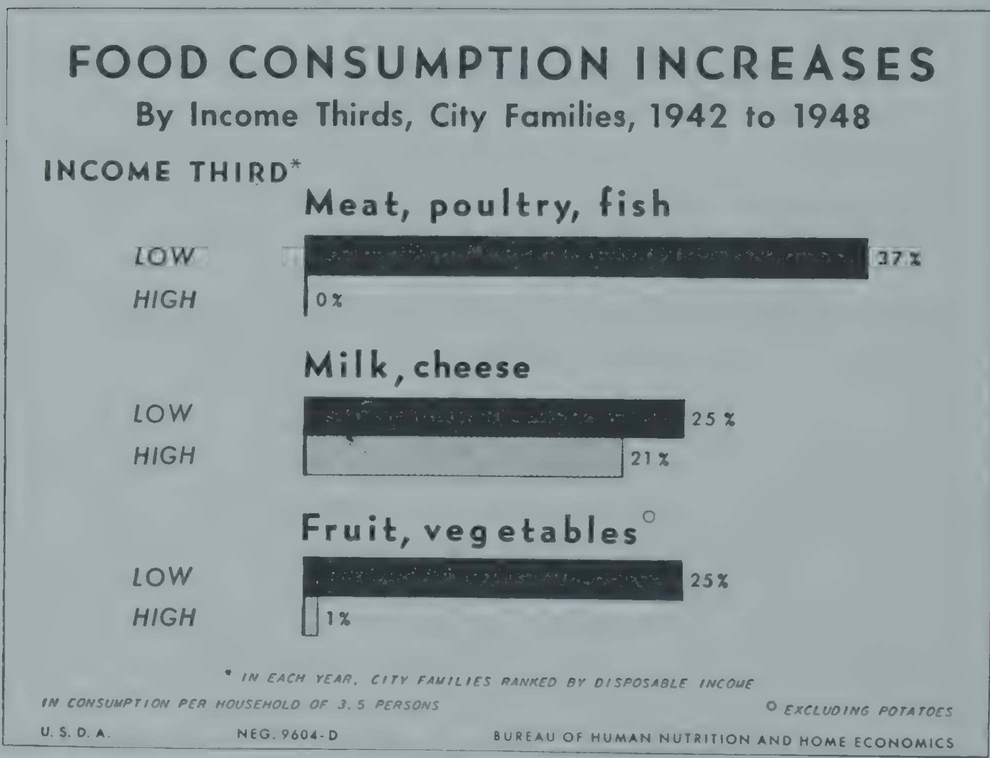

Fig. 32. Changes between 1942 and 1948 in the consumption of certain food groups by higher- and lower-income families. Each group increased its use of dairy products in 1948 over that in 1942. On the other hand, the consumption of meat, poultry, and fish and of fruits and vegetables by the higher-income group was practically the same in 1948 as in 1942; whereas consumption of these food groups by the lower income families substantially increased between 1942 and 1948. (Courtesy of the U.S. Department of Agriculture.)

special concentration on four cities, Birmingham, Alabama, San Francisco, California, Buffalo, New York, and Minneapolis-St. Paul, Minnesota, where surveys were repeated two or three seasons. The nationwide survey was believed to have yielded figures quite directly comparable to those of a similar survey of wartime food con-

sumption made in 1942; and to afford a reliable indication of changes in habits of food use during the interval 1942–1948; while findings on the four cities which were intensively studied permit comparison between various regions of the country in their habits as to the use of food. The data were also grouped in terms of family income to facilitate assessment of economic effects.

These surveys are of interest from many points of view, especially as throwing light on the factors determining how much money is

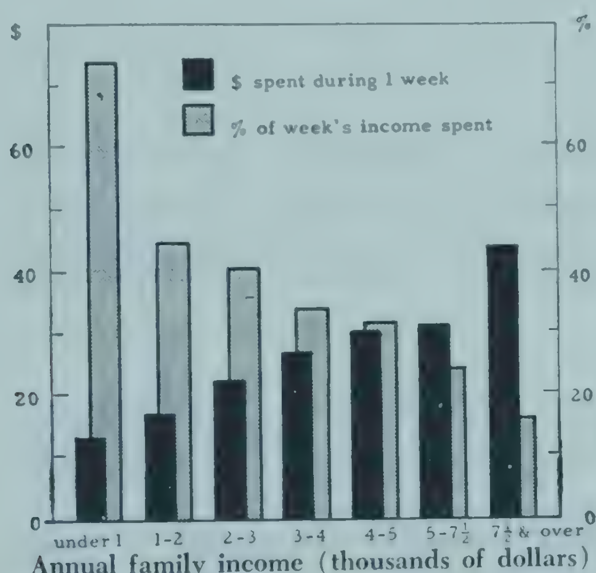

Fig. 33. Actual expenditure for food and percentage of the income spent on food in families of different incomes. (Courtesy of the U.S. Department of Agriculture.)

spent for food (and what percentage of the total income), the relative expenditure for the various kinds and types of food, and the resulting nutritive quality of the diet which it provides.

The size of the family income and the number of persons to be fed are obviously of first importance. As shown in Fig. 33 the total expenditure for food increases with increasing family income; but the percentage of the total income that is spent for food decreases as the family income increases, from 74 per cent for families with income less than $1000 to 17 per cent for families with income of $7500 and over. The total expenditure for food increases also with increasing family size, but the amount spent per member decreases (Table 33).

TABLE 33. *Family Size and Expenditure for Food**

Number in household	*Food expenditure per week per family*	*per family member*
2	$20.18	$9.66
3	24.64	8.50
4	28.15	7.49
5 or more	32.06	6.34

* Includes all income groups.

Even when allowance is made for the fact that it is often more advantageous to purchase food in quantity for a large family, and after taking into account that large families are apt to include a larger proportion of young children whose food needs are less than for adults it still seems that "the lower food expenditures of the larger families undoubtedly represent lower levels of living." This is shown to be the case in Fig. 34 which represents the adequacy

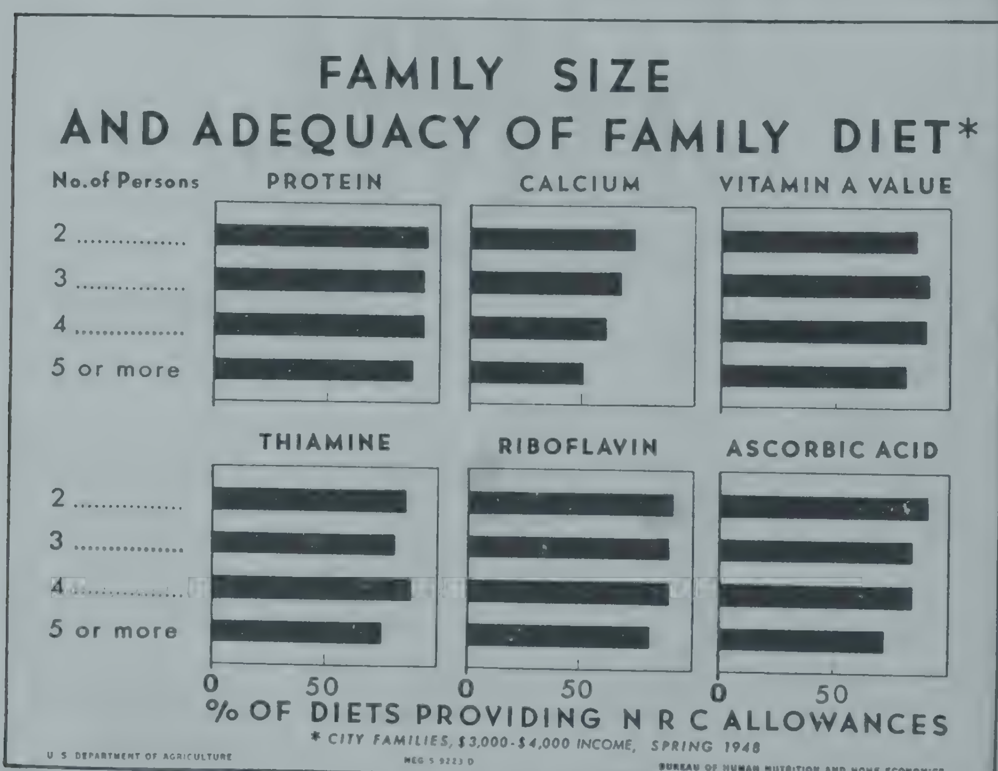

Fig. 34. The effect of family size on the adequacy of the diet in each of six nutrient factors, for families in the medium—$3000–$4000—income bracket. (Courtesy of the U.S. Department of Agriculture.)

of the diets, with respect to six nutrients, in families having an annual income of $3000 to $4000, grouped according to the size of the family. For each nutrient here considered, there was a higher percentage of large families than of small families whose diets did not provide the recommended dietary allowances—and the difference due to family size was especially evident in the cases of cal-

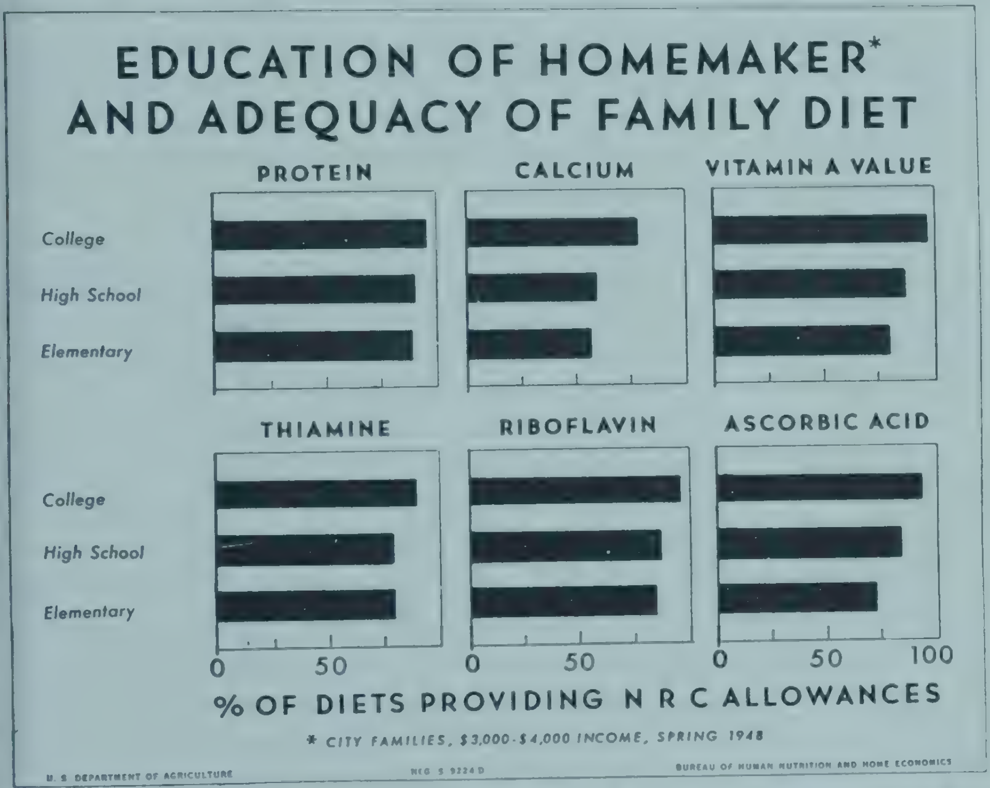

Fig. 35. The relation between the adequacy of diet of medium-income families and the amount of schooling received by the homemaker. (Courtesy of the U.S. Department of Agriculture.)

cium and ascorbic acid, the two nutrients which were considered to be most often in insufficient supply.

Of families in the same income bracket a greater proportion of those in which the homemaker had attended college received a good diet than of those in which the homemaker had completed only elementary school (see Fig. 35). The difference again was greatest when the calcium and ascorbic acid contents were considered. Considering how great a difference the amount and kinds of knowledge a homemaker has can make on the nutritive quality

of the diet she selects for her family, it is perhaps surprising that the effect of formal education beyond the elementary grades is no greater than appears here. But it will be remembered that there is a growing emphasis on teaching the importance of wise food selection to even very young children in today's schools, and that there are many sources of nutrition information outside of school—such as Home Bureau and Red Cross classes and articles in the daily papers and in homemakers' magazines. However, the number of families not receiving nutritionally good diets even though the homemaker may have a college education and the family income may be liberal, is sufficiently great to point up the need for a continuing educational program.

Table 34 compares the consumption of the various food groups, in 1942 and in 1948, by the lower-income families as compared with the higher-income families. It is seen that, with more money available to buy food, there is a tendency to use more fruits and vegetables (other than potatoes), more milk, meat, and eggs; while, on a restricted income, greater use must be made of the grain products and of the dry legumes. It is interesting, however, to point out that the *disparity* between the higher-income and the lower-income families in the consumption of meat and of citrus fruits decreased between 1942 and 1948; the lower-income group having greatly increased their use of these foods while the high-income group used no more in 1948 than in 1942. In a lesser degree this appears to be true also of the leafy, green, and yellow vegetables. On the other hand, both higher- and lower-income families increased markedly their consumption of eggs and (less markedly) their use of milk and of "other vegetables and fruits;" while reducing their consumption of potatoes and sweetpotatoes, between 1942 and 1948.

Economic Problem of Food Supply

One way of putting the problem of the best use of food is to ask the question: just what prominence is, or should be, given to each food (or type of food or food group) in the dietary of a given individual or family, or in a community or national food supply? What has been and is the custom of typical American families in this respect? Dietary studies designed to answer this question have been made in large numbers in American families (though not at

TABLE 34. *Weekly Consumption of 11 Food Groups by City Families with 3.5 Persons per Household: for the one-third of the families with the lowest income and the one-third of the families with highest income, 1942 and 1948**

		1942	*1948*	*1948 as % of 1942*
Leafy, green, yellow vegetables, *pounds*	low-income	6.66	7.08	106
	high-income	8.83	8.70	99
	high-income as % of low-income	*133*	*123*	
Citrus fruits, tomatoes, *pounds*	low-income	7.21	10.11	140
	high-income	14.83	13.44	91
	high-income as % of low-income	*206*	*133*	
Potatoes, sweetpotatoes, *pounds*	low-income	8.76	7.05	80
	high-income	9.19	7.20	78
	high-income as % of low-income	*105*	*102*	
Other vegetables and fruits, *pounds*	low-income	9.31	11.05	119
	high-income	13.14	15.96	121
	high-income as % of low-income	*141*	*144*	
Milk equivalent, *quarts*	low-income	11.56	13.99	121
	high-income	14.34	17.83	124
	high-income as % of low-income	*124*	*127*	
Meats, poultry, fish *pounds*	low-income	6.63	8.97	135
	high-income	11.81	11.66	99
	high-income as % of low-income	*178*	*130*	
Eggs, *dozens*	low-income	1.26	1.79	142
	high-income	1.51	2.09	138
	high-income as % of low-income	*120*	*117*	
Dry beans and peas, nuts *pounds*	low-income	1.19	1.12	94
	high-income	.77	.82	106
	high-income as % of low-income	*65*	*80*	
Grain products, *pounds*	low-income	10.37	10.54	102
	high-income	8.88	8.78	99
	high-income as % of low-income	*86*	*83*	
Fats and oils, *pounds*	low-income	3.75	4.01	107
	high-income	4.02	3.80	95
	high-income as % of low-income	*107*	*95*	
Sugar, sweets, *pounds*	low-income	3.07	4.90	160
	high-income	3.57	4.84	136
	high-income as % of low-income	*116*	*99*	

* Data from *Agriculture Information Bulletin No. 132*, U.S. Department of Agriculture 1954.

regular intervals) throughout the first half of the twentieth century. A series of 224 such studies widely distributed as to time, place, and economic levels yielded the average data shown in Table 35. It is believed that these findings are fairly representative of the food habits of the people of the United States in the last decade of the nineteenth and the first quarter of the twentieth centuries.

Correspondingly it is believed that a comparison of the data of Table 35 with those of Table 29 (data of 1948) show the trend of the first generation of the people of the United States to whom was

TABLE 35. *Average Percentage Distribution of Cost and Nutrients in 224 American Dietaries, Representing Period 1890–1925*

Type of Food	*Relative Cost*	*Calories*	*Protein*	*Phosphorus*	*Calcium*	*Iron*
Meat and fish	32.19	18.99	35.34	26.36	3.86	30.37
Eggs	5.47	1.77	4.64	4.02	3.64	6.25
Milk and cheese	10.59	8.08	11.56	20.61	55.76	5.11
Butter and other fats	9.55	10.32	0.31	0.32	0.73	0.33
Grain products	18.29	38.20	37.25	30.27	15.67	25.87
Sugar and molasses	4.57	10.06	0.14	0.20	1.81	1.80
Vegetables	10.55	9.05	9.55	15.58	14.87	26.42
Fruit	5.31	2.99	0.78	1.82	3.15	3.29
Nuts	0.15	0.14	0.11	0.13	0.07	0.09
Food adjuncts	3.33	0.40	0.32	0.69	0.44	0.47

available the guidance of the earlier phases of the newer knowledge of nutrition.

The average food values per man per day for the dietaries shown in Tables 35 and 29 were calculated as shown in the table on page 389.

Comparing our consumption of nutrients with the amounts required for normal nutrition (as summarized in previous Chapters) it will be seen that the freely chosen dietaries contained in the average a more liberal surplus of protein, phosphorus, and iron than of calcium. Comparing the 1948 dietaries with those of 1890–1925, the rise in calcium intake is notable as reflecting the impact of the newer knowledge of nutrition. Still, we find that the number of individual family dietaries deficient in calcium is high enough to cause serious concern. Thus of all the urban families surveyed, 42.2

	Food Value per Man per Day in*			
	Dietaries of 1890–1925 (Table 35)		*Dietaries of 1948 (Table 29)*	
Energy	3256	Calories	3040	Calories
Protein	106	grams	93	grams
Phosphorus	1.63	"		
Calcium	0.74	"	1.10	gram
Iron	17.9	mgm.	16.7	mgm.
Thiamine			1.85	"
Riboflavin			2.33	"
Niacin			19	"
Vitamin C			153	"
Vitamin A value			9100	International Units

* Based on the quantities of food as they came into the house, making no provision for waste or for losses in nutritive value during cooking.

per cent had calcium intakes less than 1.0 gram per person per day. Eleven per cent of the families had per capita intakes of protein below the generous 70 gram "recommended allowance" of protein, but only 0.8 per cent fell below the 45 gram level which is now considered to meet the normal "need." Comparing the intakes with recommended allowances for various other nutrients, it was found that, *as the food enters the house*, it falls short in vitamin C in about one-tenth of the households; and that a similar fraction applies to the thiamine and to the riboflavin contents of the food as purchased. However, the experts who analyzed the figures gathered in the survey felt that, if allowance were made for the large average losses of vitamin C in cooking, it would be found that as many as one-quarter of the families had *actual intakes* below those recommended. They therefore place vitamin C next after calcium as the nutrient factor most apt to be insufficiently provided.

Table 29 shows both the relative expenditures for the different food groups and the relative proportions of the various nutrients which these food groups contributed (in the nationwide 1948 survey of city families). Comparing column 2 (percentage of food energy) with column 1 (percentage of food cost), we find the sugars, the fats, the grain products, and the dried legumes the most economical sources of food energy. Of these, however, the fats and the

sugars contribute relatively little of protein, mineral elements, and vitamins; whereas the grain products are seen to be outstandingly economical sources of protein, iron, thiamine, riboflavin, and niacin, and even of calcium provide more than their pro rata share; and the dried legumes contribute protein, iron, thiamine, and niacin in proportions far exceeding their cost, and of calcium and riboflavin,

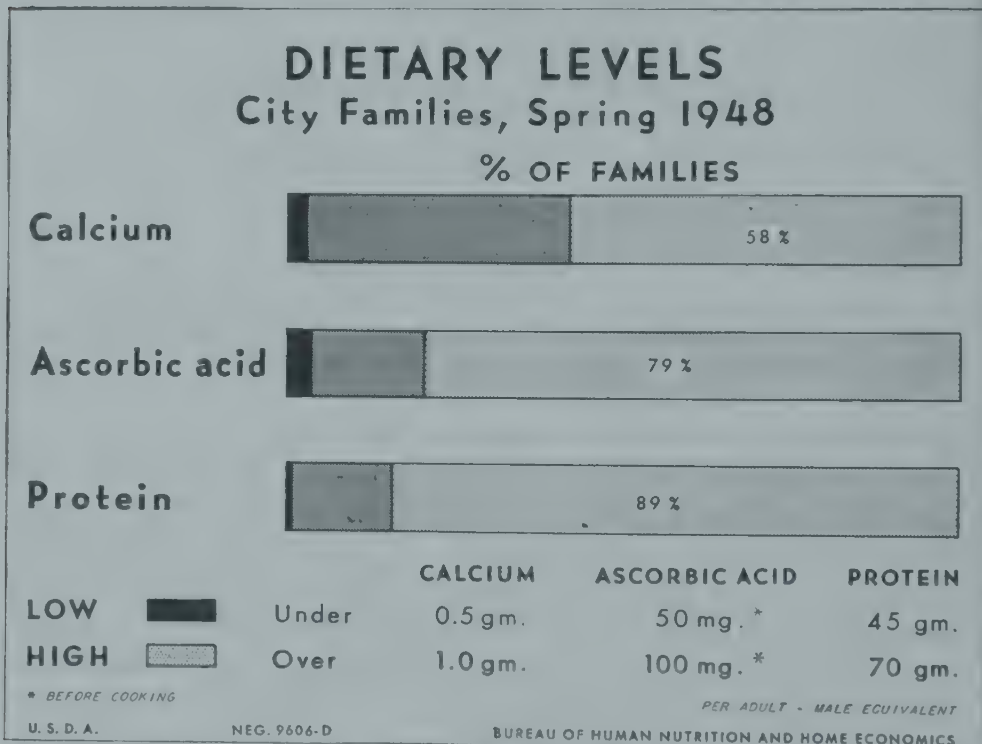

Fig. 36. Distribution of city family dietaries with respect to their contents of calcium, ascorbic acid, and protein, respectively. For this comparison, the intake level in each case has been expressed "per adult-male equivalent." Note also that the nutrient values are *before cooking* and so doubtless overestimate the actual intake to a significant extent in the case of ascorbic acid. (Courtesy of the U.S. Department of Agriculture.)

their full share. Similarly, as already noted in Chapter 19, potatoes-and-sweetpotatoes contribute more than their "quota" (on a cost basis) of all the nutrients here considered except calcium and perhaps riboflavin. It would seem therefore that even where there is great need for economy in the purchasing of food, substantial improvement in nutritive quality could result from a shift of part of the customary expenditure for sugars and fats to such other low-cost foods as grain products, dry legumes, and potatoes.

From the other point of view, considering now those nutrients in which these all-round low-cost foods tend to be least rich, we see that, *in economy as source of calcium and of riboflavin, milk* far exceeds all other food groups; while, for *vitamin C* the "best buy" is *citrus fruit and tomatoes;* and, for *vitamin A value,* the *leafy, green, and yellow vegetables.* Thus, these three groups have an important place in even the lowest-cost dietaries. And by careful selection *within* each group, large economies may still be effected, for example by use of lower cost canned (and otherwise preserved) forms of these foods.

Economy of Preservation and Distribution of Food

Preservation of a food in different forms may be important both economically and as diversifying the diet. Milk-producing regions remote from fresh-milk markets can often ship out canned and dried milk. In isolated areas where milk is not produced and even in localities where fresh milk is readily available, evaporated and dried milk may thus be much lower in price and so merit liberal use in low-cost diets.

Nutritionally equivalent amounts of different forms of milk are shown in Table 36.

TABLE 36. *Approximate Quantities of Other Dairy Products Which are Equivalent to One Quart Fluid Whole Milk*

	in protein	*in calcium*	*in riboflavin*
Evaporated milk	2 cups (17 oz. by weight)	2 cups	2 cups
Dried whole milk	scant 1 cup (4 oz.)	scant 1 cup (4 oz.)	scant 1 cup (4 oz.)
Dried skim milk	3/4 cup (3 oz.)	3/4 cup (3 oz.)	3/4 cup (3 oz.)
Cheddar cheese	5 oz.	5½ oz.	14 oz.
Cottage cheese	6 oz.	2½ lbs.	19 oz.
Ice cream	3 pints	3 pints	3 pints

A few explanatory facts will make this statement of equivalents more explicit:

In the commercial preparation of dried whole milk there is no separation of constituents except removal of most of the water

originally present in the whole fresh milk, and relatively slight diminution of some of the vitamin values. In the preparation of evaporated milk the object is the same except that removal of water is not carried so far. The aim is a concentrated form of milk which can be restored to the composition of the original fresh whole milk. This ideal is very nearly realized, the known effects upon nutrients being only doubtfully measured diminutions of the thiamine and vitamin C contents.

Returning to the above-tabulated equivalencies between milk and some of its staple products, it may be noted that the comparison of milk with cheese or ice cream is somewhat less logical than with dried and evaporated milks, because in cheese-making a part of the nutrients of the milk are lost in the whey, and in making ice cream the nutrients are diluted with sugar and other flavoring materials (and sometimes with fruit or nuts) and then there is also incorporated a considerable (and variable) proportion of air which increases the volume without appreciably changing the weight.

In the tabulation of equivalencies it is seen that Cheddar cheese and cottage cheese are similar when protein is the basis of comparison, but widely different when the calcium content is considered. This is because in cheesemaking coagulation with rennet retains most of the milk calcium in the cheese whereas, on souring, much the largest part of the milk calcium is lost in the whey. By either method of cheesemaking some riboflavin is lost in the whey, so that a greater amount of cheese is required to be equivalent to a quart of milk in riboflavin value than in protein value.

Ice cream, though it cannot be commended on grounds of economy, is seen to be a significant contributor of the nutritive factors for which we value milk; and it is a product which has been gaining rapidly in popularity (see Table 31).

Just as canned and dried milks represent a nutritionally acceptable substitute for fresh fluid milk at only a fraction of its cost, so the canned citrus juices and the frozen concentrated citrus products carry practically the same vitamin C value as the fresh fruit and are often substantially cheaper. Of the leafy, green, and yellow vegetables, carrots tend to be moderate in price most of the year; while canned forms of the others can be regarded as having retained most of the vitamin A value of the fresh vegetable (though they may have lost an important fraction of their vitamin C).

Simple Food Budgets

Based apparently upon a recommendation originally made by Miss Lucy Gillett, the following simple food budget for city families has been widely quoted and found useful:

Divide your food money into fifths—
One fifth, more or less, for vegetables and fruit;
One fifth, or more, for milk, cream, ice cream, and cheese;
One fifth, or less, for meats, fish, poultry and eggs;
One fifth, more or less, for bread and cereals;
One fifth, or less, for fats, sugar, and other groceries and food adjuncts.

The suggestion that about a fifth of the total food money be spent for bread and cereals aims at making a dietary more economical than the American average. In practice, the proportion spent for bread and cereals may (and usually does) vary with the need for strict economy. It must usually be high in an extremely low-cost dietary and may be considerably lower where the level of expenditure is more liberal.

Whatever the level of expenditure, however, it seems wise to observe the two suggestions that:

(1) at least as much should be spent for milk (including cream and cheese if used) as for meats, poultry, and fish; and

(2) at least as much should be spent for fruits and vegetables as for meats, poultry, and fish.

These latter suggestions seem to have been found useful as a guide in both low-cost and liberal-cost food budgets and can obviously be applied in all cases in which even the simplest of records of expenditures are kept. They tend to make milk, vegetables, and fruits more prominent than in the average American dietary of the present or of the recent past, and we have several scientifically sound reasons for considering this a nutritional improvement.

From among the dietary records averaged in Table 35, 25 were taken at random and a calculation was made to see how their nutritive values would have been affected if, with no change in the amount of money spent or in the kinds of foods selected, the quantities of the different food groups had been simply readjusted in accordance with the two suggestions just given. It was found that such readjustment would leave the protein practically unchanged

in amount while the calories and iron would be slightly increased and the calcium and phosphorus materially increased and brought into better quantitative relations with each other. Furthermore, the dietaries thus adjusted would undoubtedly be improved in their vitamin A and C values, and in their riboflavin contents. And these three vitamins play such important parts in the building of the higher health that increased amounts of them in the diet mean an important gain in the constructive up-building of positive health and earning power.

That progress in this direction is already taking place, gradually but upon a large scale, is shown both by the U.S. Department of Agriculture's statistics of production, consumption, and railway transportation of different types of food, and by widespread studies of food habits.

The term *protective foods* was coined by McCollum and (as already noted) first applied only to milk and the green leaf vegetables, as being the two types of food rich in both the two factors, calcium and vitamin A value, which he had come to regard as most often deficient in the dietaries of American and European peoples.

The research findings of more recent years have extended this conception in two ways. We have come to realize that enrichment of the dietary in vitamin C and riboflavin, as well as in vitamin A and calcium, is usually beneficial; and this not merely for protection against actual deficiency, but also for the promotion or enhancement of vitality, of "positive," or "buoyant," or better-than-average, health. Thus the idea has, perhaps, already outgrown the literal meaning of the word "protective"; but the term continues to do service with an enlarged and more constructive significance.

In this sense, and with the objective broadened to include the enrichment of the diet in the four factors, calcium, riboflavin, and vitamins A and C, we now apply the term protective foods to fruit, vegetables, and milk, with or without eggs. Milk furnishes all four of the chemical factors just mentioned and is an outstanding source of three of them; while each of the other three types of food just mentioned is regarded as a good source of some two of the four factors. The richness of eggs in vitamin A and riboflavin fully entitles them to admission to this category according to this latter

criterion, and the vitamin D and iron content of eggs and the high nutritive value of their proteins are all nutritional assets, especially for the growing child; but eggs do not, like fruits, vegetables, and milk, have the property of reducing intestinal putrefaction and promoting the development of a wholesome bacterial flora in the digestive tract. For this and some other reasons eggs are more cautiously emphasized, while of milk, fruit, and vegetables we now believe that (within reason) the larger the proportion of the needed calories taken in the forms of fruit, vegetables, and milk the better.

There has for some years been a steady and well-justified trend toward higher nutritional appreciation of the fruits and vegetables; and this trend continues. Hence it is an expression of the consensus of nutritional findings and opinion (and not merely, though also, of the judgment of the present writers) that we recommend for fruits and vegetables a still greater prominence in the dietary (or food budget) than is found in most previous books and bulletins.

Stiebeling's studies of food consumption at different economic levels show that as purchasing power rises from levels of severe poverty to those permitting more freedom in the choice of food, there is at first an increase in fruit and vegetable consumption fully proportionate to the increased per capita expenditure for food. But with still more comfortable levels of expenditure the extra food money does not go as largely to increased consumption of fruits and of succulent vegetables as would be desirable. In other words the consumer demand represented by the nation-wide data of about 1933–37 is responsive to, but not yet fully abreast of, the guidance of modern knowledge. Consumers still are too apt to think that about two pounds a day of fruits and vegetables is as much as they are justified in eating, whereas our present nutritional viewpoint is that certainly a third pound of per capita consumption of total fruits and vegetables (and very probably more) is an excellent investment.

Prominence of milk, fruits, and vegetables in the dietary ensures liberal intakes of calcium, riboflavin, and vitamins A and C; and, perhaps in somewhat less prominent but still important degree, of phosphorus, iron, thiamine, and niacin. If all white bread is *enriched* the intake of iron, thiamine, and niacin is further enhanced.

With all the breadstuffs and cereals enriched or whole-grain and

with fruits, vegetables, and milk (including cheese, cream, and ice cream) given due prominence in the dietary, the newer knowledge of nutrition comes effectively into the service of the family food economy.

Stiebeling and Phipard (1939), in the general summary of their findings from the study of about 4000 family food-consumption records representing 43 cities or towns in eight major geographical regions of the United States during the period December 1934 to February 1937, point out that the *average* dietaries of this period (while already showing some effects of the teachings of the newer knowledge of nutrition) included only one-half to two-thirds as much milk and less than two-thirds as much of fruits and vegetables as did the dietaries which they graded as good, and add: "But even these *good* diets fell short of the allowances of these protective foods believed by many authorities to be optimal."

Most of these 4000 families spent between 25 and 40 per cent of their income for food. On the average, those having more money to spend for food increased their purchases of milk, butter, cream, eggs, meats, fruits, and succulent vegetables in greater degree than their purchases of grain products, sugars, and fats other than butter. Thus when total food expenditure was 200 per cent higher, that for fruits was 200 to 400 per cent higher but that for grain products and fats other than butter was only about 30 to 35 per cent higher.

Thus the newer knowledge of nutrition does not suggest any serious departure from the natural inclinations of present-day American consumers: rather it offers guidance and "implementation" for the realization of the fullest measure of satisfaction from a movement in the direction in which most consumers already wanted to go.

But for even a reasonable approach to best results the teaching of greater prominence of fruits, vegetables, and milk (including cheese, cream, and ice cream) in our dietaries and food supplies should be emphasized and practiced in higher degree than now.

Stiebeling and Phipard find that in every region studied families spending only small amounts of money for food use only small quantities of milk. And in the average of all the white families studied, while one-fourth to one-third of the food money was spent for meat, fish, poultry, and eggs, only one-fifth to one-fourth was

spent for fruits and vegetables, and only one-eighth to one-sixth for milk and cheese. (The negro family food budgets showed still less appreciation of fruits, vegetables, and milk.)

Progress in the direction of giving higher place in the dietary to fruits, vegetables, and milk is more evident in the feeding of children than of grown people.

The data of Table 38 were adapted with the approval of the late Dr. Mary S. Rose from her teaching of "working plans for the construction of adequate diets."

TABLE 38. *Rose's Recommendations (Adapted)*

	Percentage of Total Calories from Fruits, Vegetables, and Milk
For Children	
1– 2 years	70–85
2– 3 "	65–72
3– 4 "	62–69
4– 5 "	59–68
6– 7 "	54–60
8– 9 "	53–58
10–12 "	51–56
For High-School Boys and Girls	
at 2000 Calories	48–53
" 2500 "	42–45
For Healthy Adults on Low to Moderate Incomes	28–30
For a Family of 2 Adults and 3 Young Children on Low to Moderate Income	37–42

Table 39 shows the "distribution standards" for children's dietaries recommended by Dr. Rose and Table 40 a differentiation according to economic level.

Table 40 shows corresponding distribution standards to guide the planning of minimum cost and moderate cost dietaries, respectively, for children of ages 5 to 16 years. The minimum-cost standard is based on the recommendations of the Committee on Economic Standards of the New York Nutrition Council. The moderate-cost standards are those used by Rose and Gray in judging the dietaries of child-caring institutions.

For family groups Stiebeling's "dietaries at four levels of cost"

TABLE 39. *Distribution of Calories in Diets of Children of 4 to 12 Years*

Age in Years	Per Cent of Total Calories from Each Class of Food					
	Foods from Cereal Grains	Milk	Vegetables and Fruits	Fats*	Sugars and Sweets	Eggs, Cheese, Meat, and Other Flesh Foods
4–5	23–25	45–50	14–18	5–8	2–5	5–6
5–6	23–25	45–50	14–18	5–8	2–5	5–6
6–7	20–25	40–45	14–15	10–12	3–4	4–5
8–9	20–25	38–42	15–16	12–13	4–6	5–6
10–12	20–25	34–38	17–18	13–14	6–8	7–8

* At least part of the fat to be butter or something known to furnish its equivalent of vitamin A.

TABLE 40. *Distribution of Calories in Diets of Minimum and of Moderate Cost for Children of Ages 5 to 16 Years*

Food Group	Minimum-Cost Diet	Moderate-Cost Diet
	Per Cent of Total Calories	Per Cent of Total Calories
I. Foods from cereal grains	37	24
II. Milk	22	32
III. Vegetables and fruits		
A. Dried legumes	3	1
B. Other vegetables and fruits	13	16
IV. Fats and oils	14	12
V. Sugars and sweets	5	7
VI. Meat, eggs, cheese	6	8

and supplementary suggestions will afford much additional guidance. An independent discussion based essentially upon them has also been published by Hambidge. (See Suggested Readings at the end of the chapter.)

Omitting the emergency diet, Stiebeling and Ward's recommendations were as shown in Table 41. McCollum's recommendation for milk consumption is one quart per capita per day. Inasmuch as new research findings, since 1933 when the recommendations of Stiebeling and Ward were published, tend strongly to raise

TABLE 41. *Yearly per Capita Consumption of Foods at Different Economic Levels as Recommended by Stiebeling and Ward*

Food		*Adequate Diet at Minimum Cost*	*Adequate Diet at Moderate Cost*	*Liberal Diet*
Milk*	*quarts*	260	305	305
Potatoes, sweetpotatoes	*lbs.*	165	165	155
Dried beans, peas, nuts	"	30	20	7
Tomatoes, citrus fruits	"	50	90	110
Leafy, green, and yellow vegetables	"	80	100	135
Dried fruits	"	20	25	20
Other fruits and vegetables	"	85	210	325
Flour, cereals	"	224	160	100
Fats†	"	49	52	52
Sugars	"	35	60	60
Meats, poultry, fish	"	60	100	165
Eggs	*dozens*	15	15	30

* Including such milk products as share its essential nutritional characteristics. The approximate equivalents are given in Table 36.

† In the data of this table, bacon and fat pork are included under Fats and not under Meats.

the estimate of optimal intake of calcium and riboflavin, we believe that this is a sound reason for preferring 365 quarts rather than 305 quarts of milk per capita per year.

Also we believe that the trend of advance of nutritional knowledge since 1933 makes it logical to give an even more prominent place to fruits and vegetables in the dietary than is given in the Stiebeling and Ward recommendations.

We may repeat here the recommendation: (1) that at least half the total calories be taken in the form of fruit, vegetables, and milk (including cheese, cream, and ice cream); and (2) that at least half the cereals and breadstuffs consumed be in approximately whole-grain forms, with all white bread enriched.

Food Budgets as Guided by Nutritional Knowledge

The Bureau of Human Nutrition and Home Economics has prepared, and the U.S. Department of Agriculture has issued as its

Miscellaneous Publication No. 662, a booklet entitled, "Helping Families Plan Food Budgets."

The following excerpts from it are appropriate to our present discussion.

Gauging a family's nutritional needs. To measure the nutrients needed by a given family, account must be taken at all age levels of the size and activity of each member. The dietary allowances for children are based on average needs for the middle year in each age group. They are for children of normal activity and average weight and height. If, however, children vary considerably from average weight and height for their age, the quantities in the next higher or lower age group may be more suitable.

For adults, the Recommended Dietary Allowances are based on the needs of a 154-pound man and a 123-pound woman, both of average height. Men and women considerably above or below the average in stature may have a higher or lower calorie requirement. Since many adults think of themselves as more active than they really are, the following illustrations of activity are given:

"Sedentary" persons do office work, clerking in a store, or housekeeping for a small family—the kind of work that calls for comparatively little muscular effort.

"Active" men do work like carpentering, ordinary farm labor, or factory work. *"Moderately active" women* do work such as waiting on tables or housekeeping for a moderate-sized family.

Men at "heavy work" spend 8 hours or more a day at such work as lumbering, ditch digging, or heavy farm labor. *"Very active" women* do work such as heavy housework at least 8 hours a day.

A person's activities apart from his job are also important. For example, a man who walks to and from work and spends several hours working in a garden or around the house may be in the active classification even though his job is considered sedentary.

The energy needs of many persons will fall midway between two of the classifications.

Master food plans. The nutrients for an adequate diet can be provided by many different combinations of food. Three master plans for meeting the requirements, two at low cost and one at moderate cost, are given in Tables 43, 44 and 45. In these plans the Recommended Dietary Allowances[1] are translated into terms of

[1] Given in full in Table 48, Appendix.

TABLE 42. *Food Groups and Approximate Number of Servings per Person, Low-cost and Moderate-cost Plans*

*Food Groups**	*Number of Servings per Person*	
	Low-cost Plan (Table 43)	*Moderate-cost Plan (Table 44)*
Leafy, green, and yellow vegetables	7 to 9 servings a week	10 to 12 servings a week
Citrus fruit, tomatoes	Children, 7 servings a week Pregnant and nursing women, 9 to 12 servings a week Other adults, 6 or 7 servings a week	Children, 8 to 9 servings a week Pregnant and nursing women, 12 to 15 servings a week Other adults, 7 to 9 servings a week
Potatoes, sweetpotatoes	10 to 12 servings a week	7 to 9 servings a week
Other vegetables and fruit	7 servings a week	10 to 12 servings a week
Milk, cheese, ice cream (In terms of fluid milk)	Children, about 3½ cups of milk a day Pregnant women, 1 quart daily Nursing women, 1½ quarts a day Other adults, 2 cups a day	Children, 3½ to 4 cups milk a day Pregnant women, 1 quart daily Nursing women, 1½ quarts a day Other adults, 2 to 2½ cups a day
Meat, poultry, fish	5 or 6 servings a week	7 or 8 servings a week
Eggs	5 eggs a week	7 eggs a week
Dry beans and peas, nuts	2 to 4 servings a week	1 to 2 servings a week
Flour, cereal, baked goods (Whole-grain, enriched, restored)	Bread at every meal and also a cereal dish once a day	At every meal
Fats, oils	Throughout the week as desired. Butter or margarine daily	Throughout the week as desired. Butter or margarine daily
Sugar, sirup, preserves	Throughout the week as desired	Throughout the week as desired

* In addition to the foods in the 11 groups, fish-liver oil or some other source of vitamin D should be allowed for small children, pregnant and nursing women, also for older children and adults who have little opportunity for being in sunshine.

There are also certain miscellaneous food items to be considered in the total food plan. The miscellaneous group includes such items as coffee, tea, cocoa, chocolate; salt, pepper, other seasonings, and flavorings; baking powder and soda; prepared puddings and gelatin. No quantities are suggested for these items but allowance is made for their cost.

food. Foods are classified in 11 groups and the quantities needed weekly are given for persons in each of 19 age, sex, and activity groups. From these, plans for families of different sizes and composition can easily be made.

These plans are flexible enough to fit various seasons, places, and family tastes, as well as to provide variety in meals from day to day and week to week. Tables 43 and 45 are for low cost and Table 44 for moderate cost.

Food quantities in terms of servings. In planning menus based on food-group quantities, it is helpful to have the suggested pounds and quarts of foods translated into approximate numbers of servings. This is done in Table 42.

Selecting the plan to fit the budget. Before families can decide whether to use the low-cost or the moderate-cost food plan, they will need to know about how much money is needed for each. They must also consider food cost in relation to their total budget. . . . Studies show that on the average, with a higher income, more dollars but a smaller percentage of income goes for food. With equal incomes, large families spend more for food per family but less per person than do small families. The actual cost to a family of the food in these plans depends on a number of things—current prices, the community in which the family lives, and whether the family buys in quantity, shops around for bargains, or produces some food at home. For families who must buy all of their food, the weekly cost of the foods in these plans was about as follows at March 1956 city food price levels:

Family Members	*Low-cost Plan**	*Moderate-cost Plan*
Family of 2 persons (active man, sedentary woman)	$13	$16
Family of 4 persons (active man, moderately active woman, children 7–9 and 10–12 years)	$21	$25
Family of 4 persons with young children (active man, moderately active woman, and children 1–3 years and 4–6 years)	$18	$22
Family of 6 persons (active man, moderately active woman, boy 16–20 years, girl 13–15 years, and children 7–9 and 10–12 years)	$32	$39

* See also Table 45 for an additional low-cost plan.

TABLE 43. *Master Food Plan at Low Cost. Weekly quantities of food (as purchased) for 19 age, sex, and activity groups* (1955 Interim revision of U.S. Department of Agriculture *Miscellaneous Publication No. 662*)

Family members	*Leafy, green, and yellow vegetables*	*Citrus fruit, tomatoes*	*Potatoes, sweetpotatoes*	*Other vegetables and fruit*	*Milk*[a]	*Meat, poultry, fish*	*Eggs*	*Dry beans and peas, nuts*	*Flour, cereals*[b]	*Fats and oils*[c]	*Sugar, sirups, preserves*
	Lb. Oz.	*Lb. Oz.*	*Lb. Oz.*	*Lb. Oz.*	*Qt.*	*Lb. Oz.*	*No.*	*Lb. Oz.*	*Lb. Oz.*	*Lb. Oz.*	*Lb. Oz.*
Children:											
1–3 years	1—12	1—12	1— 0	1— 0	5	0— 8	5	0— 1	1— 4	0— 2	0— 2
4–6 years	1—12	1—12	1— 8	1— 4	5	1— 0	5	0— 2	1—12	0— 6	0— 6
7–9 years	2— 0	2— 0	2— 8	1— 8	5	1— 8	5	0— 4	2— 4	0— 8	0—10
Girls, 10–12 years	2— 4	2— 4	2— 8	1—12	6	1—12	5	0— 4	2— 8	0—12	0—10
13–15 years	2— 4	2— 4	3— 0	1—12	6	2— 0	5	0— 4	3— 0	0—12	0—10
16–20 years	2— 4	2— 4	2—12	1—12	6	[d]2— 0	5	0— 4	2—12	0—12	0—10
Boys, 10–12 years	2— 4	2— 4	3— 0	1—12	6	2— 0	5	0— 4	3— 0	0—12	0—10
13–15 years	2— 8	2— 8	4— 0	2— 4	$6\frac{1}{2}$	2— 0	5	0— 8	4— 4	1— 0	0—14
16–20 years	2—12	2— 8	5— 0	2— 8	$6\frac{1}{2}$	2— 0	5	0— 8	5— 8	1— 6	1— 0
Women:											
Sedentary	2— 4	2— 0	2— 4	1—12	$3\frac{1}{2}$	2— 0	5	0— 4	2— 0	0—10	0—10
Moderately active	2— 4	2— 0	2—12	1—12	$3\frac{1}{2}$	2— 0	5	0— 4	3— 4	0—12	0—12
Very active	2— 8	2— 8	3—12	2— 4	$3\frac{1}{2}$	2— 0	5	0— 6	4— 0	1— 0	1— 0
Pregnant	3— 0	2— 8	2— 8	2— 0	7	2— 4	7	0— 4	2— 8	0—10	0— 8
Nursing	3— 8	3—12	4— 0	2— 4	10	2— 8	7	0— 4	3— 0	0—10	0— 8
60 years or over	2— 8	2— 4	2— 4	1—12	$3\frac{1}{2}$	2— 0	4	0— 2	2— 0	0— 8	0— 8
Men:											
Sedentary	2— 4	2— 0	2—12	1—12	$3\frac{1}{2}$	2— 0	5	0— 4	3— 4	0—12	0—12
Physically active	2— 8	2— 8	3—12	2— 4	$3\frac{1}{2}$	2— 0	5	0— 6	4— 0	1— 0	1— 0
With heavy work	2— 8	2— 8	5— 8	2—12	$3\frac{1}{2}$	2— 0	5	0—10	7— 0	1—14	1— 0
60 years and over	2— 8	2— 4	3— 4	1—12	$3\frac{1}{2}$	2— 0	4	0— 2	3— 4	0—10	0—10

[a] Or its equivalent in cheese, evaporated milk, dry milk, or ice cream. (See Table 36.)

[b] Count $1\frac{1}{2}$ pounds of bread as 1 pound of flour. Use as much as possible in the form of whole-grain, enriched, or restored products.

[c] For small children and pregnant and nursing women, cod liver oil or some other source of vitamin D is also needed. For elderly persons and for persons who have no opportunity for exposure to clear sunshine, a small amount of vitamin D is also desirable.

[d] To meet iron allowance, 1 large serving of liver or other organ meats should be served each week.

TABLE 44. *Master Food Plan at Moderate Cost. Weekly quantities of food (as purchased) for 19 age, sex, and activity groups* (1955 Interim revision of U.S. Department of Agriculture *Miscellaneous Publication No. 662*)

Family members	Leafy, green, and yellow vegetables	Citrus fruit, tomatoes	Potatoes, sweetpotatoes	Other vegetables and fruit	Milk[a]	Meat, poultry, fish	Eggs	Dry beans and peas, nuts	Flour, cereals[b]	Fats and oils[c]	Sugar, sirups, preserves
	Lb. Oz.	Lb. Oz.	Lb. Oz.	Lb. Oz.	Qt.	Lb. Oz.	No.	Lb. Oz.	Lb. Oz.	Lb. Oz.	Lb. Oz.
Children:											
1–3 years	1—12	1—12	1—0	1—12	5½	0—12	6	0—1	1—4	0—2	0—2
4–6 years	2—0	2—0	1—4	2—0	6	1—4	7	0—1	1—8	0—6	0—8
7–9 years	2—4	2—4	2—0	2—8	6	1—12	7	0—2	2—0	0—8	0—12
Girls, 10–12 years	2—8	2—12	2—0	2—8	6	2—4	7	0—2	2—8	0—12	0—12
13–15 years	3—0	2—12	2—4	2—12	6	2—12	7	0—2	2—12	0—12	0—12
16–20 years	3—0	2—12	2—0	2—12	6	2—12	7	0—2	2—8	0—12	0—12
Boys, 10–12 years	2—8	2—12	2—8	2—8	6	2—4	7	0—4	3—0	0—12	0—14
13–15 years	3—8	3—0	3—8	3—4	6½	3—0	7	0—4	4—0	1—2	1—2
16–20 years	3—12	3—4	4—8	3—4	6½	3—4	7	0—4	5—0	1—6	1—4
Women:											
Sedentary	2—8	2—8	1—12	2—8	4	2—8	7	0—1	1—12	0—10	0—10
Moderately active	3—0	2—8	2—8	3—4	4	2—12	7	0—2	2—8	0—12	0—12
Very active	3—12	3—0	3—8	4—0	4	3—0	7	0—4	3—12	1—2	1—2
Pregnant	3—8	3—8	2—4	3—0	7	3—0	7	0—2	2—4	0—10	0—10
Nursing	4—0	4—8	3—0	3—8	10	3—0	7	0—2	2—8	0—12	0—12
60 years or over	2—12	2—12	1—12	2—8	4	2—8	6	0—1	1—12	0—8	0—8
Men:											
Sedentary	3—0	2—8	2—8	3—4	4	2—12	7	0—2	2—8	0—12	0—12
Physically active	3—12	3—0	3—8	4—0	4	3—0	7	0—4	3—12	1—2	1—2
With heavy work	3—12	3—8	5—0	4—8	4	3—4	7	0—6	7—0	2—0	1—8
60 years or over	2—12	2—12	2—12	2—8	4	2—12	6	0—2	2—8	0—12	0—12

[a] Or its equivalent in cheese, evaporated milk, dry milk, or ice cream (See Table 36.)

[b] Count $1\frac{1}{2}$ pounds of bread as 1 pound of flour. Use as much as possible in the form of whole grain, enriched, or restored products.

[c] For small children and pregnant and nursing women, cod liver oil or some other source of vitamin D is also needed. For elderly persons and for persons who have no opportunity for exposure to clear sunshine, a small amount of vitamin D is also desirable.

TABLE 45. *A Second Master Food Plan at Low Cost. Weekly quantities of food (as purchased) for 19 age, sex, and activity groups* (U.S. Department of Agriculture *Miscellaneous Publication No. 662*)

Family members	*Leafy, green, and yellow vegetables*	*Citrus fruit, tomatoes*	*Potatoes, sweetpotatoes*	*Other vegetables and fruit*	*Milk**	*Meat, poultry, fish*	*Eggs*	*Dry beans and peas, nuts*	*Flour, cereals†*	*Fats and oils*	*Sugar, sirups, preserves*
	Lb. Oz.	*Lb. Oz.*	*Lb. Oz.*	*Lb. Oz.*	*Qt.*	*Lb. Oz.*	*No.*	*Lb. Oz.*	*Lb. Oz.*	*Lb. Oz.*	*Lb. Oz.*
Children through 12 years:											
9–12 months	1—8	1—12	0—8	1—0	6	0—4	5	0—1	0—10	0—1	0—1
1–3 years	1—8	1—4	1—8	0—8	(5)	0—6	4	0—1	1—8	0—2	0—2
4–6 years	1—8	1—8	2—0	0—12	(5)	0—8	3	0—4	2—4	0—6	0—4
7–9 years	1—12	1—8	3—0	0—12	(5)	0—12	3	0—6	3—0	0—8	0—8
10–12 years	2—0	1—8	3—8	1—4	6	1—0	3	0—8	3—8	0—12	0—12
Girls:											
13–15 years	2—0	1—12	4—0	1—8	(6)	1—0	4	0—8	3—12	0—12	0—12
16–20 years	2—0	1—12	3—8	1—8	(6)	1—0	4	0—8	3—12	0—12	0—12
Boys:											
13–15 years	2—0	2—0	4—4	1—8	6½	1—4	4	0—12	4—12	1—2	0—14
16–20 years	2—4	2—0	5—8	1—8	6½	1—4	5	0—14	6—0	1—6	1—0
Women:											
Sedentary	2—0	1—8	3—0	1—4	(3½)	1—0	4	0—4	3—0	0—8	0—8
Moderately active	2—0	1—8	3—8	1—8	(3½)	1—0	4	0—8	3—12	0—12	0—12
Very active	2—0	1—8	4—8	1—8	(3½)	1—0	4	0—12	4—12	1—0	0—14
Pregnant	2—12	2—0	3—0	1—8	(7)	1—4	5	0—6	3—0	0—8	0—8
Nursing	3—0	3—12	4—4	1—8	(10)	1—8	5	0—6	3—8	0—12	0—8
60 years or over	2—0	1—12	3—4	1—0	(3½)	1—0	4	0—4	3—0	0—8	0—8
Men:											
Sedentary	2—0	1—8	3—8	1—8	(3½)	1—0	4	0—8	3—12	0—12	0—12
Physically active	2—0	1—8	4—8	1—8	(3½)	1—4	4	0—12	4—12	1—0	0—14
With heavy work	2—0	1—8	7—0	1—8	(3½)	1—4	5	1—0	7—12	1—14	1—4
60 years or over	2—0	1—12	4—0	1—4	(3½)	1—0	4	0—6	3—12	0—10	0—10

* Or its equivalent in cheese, evaporated milk, or dry milk. (See Table 36.) Milk allowances adjusted corresponding to interim revision of Table 43.

† Count 1½ pounds of bread as 1 pound of flour. Use as much of this as possible in the form of whole-grain, enriched, or restored products.

The original publication has somewhat fuller footnotes.

EXERCISES

1. Taking the data of Table 29 as fairly typical of such American dietaries as are only beginning to be influenced by the newer knowledge of nutrition, what changes in the distribution of the food money among the different types of food would you now recommend?

2. If the allotment of the food money were readjusted so that as much was spent for milk and cheese, and also as much for fruits and vegetables, as for meats and fish, would you anticipate an increase or a decrease: (*a*) in the calcium content of the dietary; (*b*) in its ascorbic acid (vitamin C) content; (*c*) in its thiamine content; (*d*) in its riboflavin content; (*e*) in its vitamin A value; (*f*) in the excellence of its nutritional character as a whole?

3. As it is known that meat and fruit do quite directly "compete for the consumer's food money," what effect would you anticipate from the shifting (*a*) of one-third of the customary expenditure for meat and fish to fruit instead, (*b*) of one-third of the customary expenditure for fruit to meat instead?

4. Assuming such readjustment of the food budget as you under the guidance of the newer knowledge of nutrition consider it wise to make, would this call for any essential change in the set-up of menus or meal plans, or only for increases or decreases in the sizes of servings of certain foods?

5. Make meal plans set up in the general style in Rose's *Feeding the Family* and incorporating in full your present judgment as to the best relative amounts of the different types of food.

6. Compare your individual dietary or food consumption record, or that of a family whom you know, with the suggestions of Tables 42 to 45.

Does your dietary omit any one of the eleven "kinds" into which foods are grouped in those tables? If so, is the omission an advantage or a disadvantage nutritionally? Why?

7. Having in mind the fact that recent and current research shows some foods to be better investments than we have hitherto known, could you now improve your dietary nutritionally without seriously increasing its cost?

How much money per year could be made available for the further improvement of your dietary (or that of the family you have in mind) by a partial shifting of expenditure guided by your knowledge of nutrition?

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21

HOW TO MAKE NUTRITIONAL KNOWLEDGE MORE EFFECTIVE

"Nutrition Policy"—Public and Personal

The ways of making nutritional knowledge more effective, than it has yet generally become, are sometimes grouped into three brackets as follows:

(1) Research and education in the functions of nutrients, the importance of nutrition to health and efficiency, and the wise use of food and of income;

(2) Direct economic action to promote the increased production and consumption of foods whose larger use is deemed to be nutritionally the more desirable;

(3) Improvement of the nutritional environment in which the people live by requiring certain widely used foods to be nutritionally enriched, restored, or fortified.

Following the general usage of nutritionists we here employ the phrase, *nutrition policy*, the word "policy" meaning, according to a modern dictionary,[1] primarily a definite course of action adopted as expedient or from other considerations.

That is, this chapter deals with definite courses of action looking to the ever increasingly effective use of nutritional knowledge, both as being expedient and for reasons which may be deemed higher than expediency alone. Thus some people may assert while others may deny that the United States has entered upon a policy of "school lunches" or of public support of one or another form of child feeding aiming to ensure that food adequate to the needs of full health or of good nutritional status shall be brought within

[1] *The American College Dictionary*. New York: Random House. 1948.

reach of all children of school age. But any such difference of opinion would (at this stage of the development of our civilization) probably apply only to the expediency of the particular project proposed. Nearly all would agree that for reasons of social justice if not also of expediency, each one of our United States should see that none of its children lacks food needed for full health.

Much can be said for each of the three general modes of attack upon the problem of the best use of food which have just been mentioned. Perhaps the thing which should be said first and with most emphasis is that these different approaches are all compatible with each other. Progress can and should be made in all these ways at once.

The science of nutrition is still a fertile field for research and one of the ways of making it more effective is to amplify it, and render it more precise in detail, by further research. Teaching nutrition, and using its guidance in food economics and in "the enrichment program," can all increase the effectiveness of the nutritional knowledge which we now have.

All three of these approaches to "the food problem" were used at the same time in the United Kingdom during World War II, and together they resulted in bringing the public health of England up to, and keeping it upon, a higher plane during the war than before, notwithstanding the wartime reductions of food imports and the diversion of medical service to the armed forces. Public education in foods and nutrition, nutritional guidance in the governmental control of food production and import, the legal requirement of nutritional enrichment of such a widely used food as white flour, and national control of the use of feed-stuffs and the distribution of milk, very nearly kept up the Calories of the food supply and actually increased its mineral and vitamin values with corresponding improvement of the public health.

Sir J. C. Drummond, as quoted in the *Journal of the American Dietetic Association*, has said that, after the outbreak of World War II, Great Britain had to depend for nutritional security primarily upon potatoes, mixed vegetables, and bread made from flour containing a high percentage (usually 85 per cent) of the wheat grain.

According to the data of Montgomery and Cardell, the apparent

yearly per capita consumption of sugar in the United States increased from 53 to 101 pounds, and of commercial fat from 13 to 44 pounds, between 1889 and 1927. And Ohlson, Nelson, and Swanson, using these data in their 1937 discussion, point out that this markedly increased consumption of commercial fat and sugar is largely responsible for the difficulty now experienced by home economics women in making dietaries according to "the pattern" or "the market" of today which shall be as high as is desirable in the many now recognized essentials without being too high in calories. Here the outstanding need is to recognize that the high levels of fat and sugar consumption which have crept into our dietaries during the past two generations are not to be regarded as permanent parts of our dietary pattern but as distortions which ought to be reduced rigorously to make room for more of the foods of high mineral and vitamin values.

Research and Education Policy, and Nutrition Service

It was especially to consider the broad aspects of nutrition policy that the League of Nations, under the challenge of the Delegation from Australia that something be done to "Marry agriculture and health," appointed a Mixed Committee representing nutrition, agriculture, and economics, under the chairmanship of Lord Astor, whose above mentioned declaration that, "It isn't sufficient that there be enough food; there must be enough of the *right kinds* of food," did much to give worldwide currency to this fundamental fact.

The British Medical Association took the initiative in organizing a conference on nutrition policy for Great Britain, which met in London, for the consideration of the wider aspects of nutrition, on April 27–29, 1939. Its key note recommendation was as follows: "The conference called by the British Medical Association and composed of representatives of medicine, agriculture at home and overseas, industry, and education, is deeply impressed with the importance of nutrition to the national welfare. It urges upon the Government the formulation of a long-term food policy in which the requirements of health, agriculture, and industry shall be considered in mutual relation. It is convinced that measures to secure the more ready availability, to all sections of the community, of

foodstuffs which are held to be desirable on nutritional grounds should be accompanied by an education campaign to encourage their increased consumption."

In the United States the Federal and State Governments have made many contributions to nutritional research and education, but as yet have taken only somewhat tentative steps in the way of direct economic action to increase the production of the right kinds of foods for the best nutrition of the people. As the combined results of research and education reach larger numbers of people with increasing effectiveness, these people come consciously to *want* (for themselves and others) the higher health that the newer knowledge of nutrition offers. Hence it begins to be practicable for the allotment of funds to reward right use of the land, and to purchase surplus foods for distribution in whatever may appear the most equitable way or ways, but always guided more fully by nutritional considerations than was possible in the past.

Perhaps the underlying condition most needed in order to make nutritional knowledge more effective is a keener realization, a more constant consciousness, *a conviction*, of the fact that there is (or may be) a highly significant difference between the merely adequate and the optimal in nutrition. The attempt to bring about this realization is not a hopeless task, for important progress has been made already. This is shown, for instance, by our national statistics of production and consumption of fruits, vegetables, and milk; by comparative dietary studies at a 15-year interval in New York City; and by the editorial statement in the *Journal of the American Medical Association* that the difference between merely passable health and buoyant health is coming to be more appreciated.

Farmers now know that they cannot afford to keep animals of merely passable health. The level of productiveness that makes a farm animal profitable is dependent upon a state of nutrition more nearly optimal than that which is merely adequate to pass a veterinary inspection. Gove Hambidge remarks that many a farmer would be "ashamed to feed his livestock as casually as he feeds his family;" and suggests that it would be no more than intelligent for us (with the food-production possibilities which our country affords) to build a nation of people as sturdy as the animals in a good farmyard.

The preceding paragraphs do not imply that nutrition is solely

responsible for the difference between merely passable health on the one hand and positive or bouyant health on the other. Physical education plays several parts; and heredity is a large factor in superiority both in the human family and among its domestic animals. The present point of emphasis is that *both heredity and training become more productive* when supported by the superior nutritional condition and internal environment to which our newer knowledge can serve as a guide. More can now be accomplished through nutrition than we have previously been accustomed to suppose.

In the exceedingly modest terms in which Sir Frederick Gowland Hopkins put it, "Nurture can assist Nature to a larger extent than Science has hitherto thought."

Thus a very important first step in making nutritional knowledge more effective is to train oneself, and to help others, to an adequate realization of its potentiality.

The researches of Dove at the Maine Agricultural Experiment Station indicate that the *innately superior* farm animal may owe this superiority to an hereditary endowment which guides "instinctively" to better-than-average eating habits. Then, if the other animals of the herd are fed according to his example, their level of attainment and productivity is improved. (This seems a valuable suggestion for human improvement; but one to be used with very conscientious care, lest it be perverted by citing unrepresentative cases!)

Nutrition Policy is Made Effective by Both Economic and Educational Methods

How each of us may use nutritional knowledge as effectively as possible in our own lives, and extend its benefits to the lives of as many other people as possible, is both an economic and an educational problem.

It is economic in the sense that most of us would follow the guidance of the newer knowledge of nutrition somewhat more readily, fully, and effectively if we had more money to spend for food; and in the sense of the wider view which shows that malnutrition is much more prevalent among the poor than among the well-to-do. As incomes rise above the poverty level, nutritional conditions

automatically improve. With more money to spend for food, people in general buy themselves nutritionally better food supplies than those to which the majority now feel themselves confined by the limitations of their purchasing power.

Yet at the same time, there is also an educational problem; for careful studies show clearly, as has recently been especially emphasized by Stiebeling, that a very large proportion of families can learn to have nutritionally much better dietaries than they now do, even at their present levels of expenditure for food.

Recognizing that both economic and educational problems are involved, many people are now of the opinion that the primary and fundamental need is *nutritional consciousness* or *nutrition policy*; and that when a right policy in regard to nutrition is consciously adopted, both educational and more directly economic methods will be found or made effective for its promotion.

Much has already been done by the U.S. Department of Agriculture and the State colleges and extension services in agriculture and home economics; and by state and local nutritionists and nutrition committees. And in recent years, the Red Cross has also done much for public education in nutrition.

State Nutrition Services. Nearly every state department of health now provides a nutrition service in some form. The extent of these services has been greatly augmented since the Social Security Act made federal funds available for states to strengthen their health services to mothers and children. These funds, which are administered under the U.S. Children's Bureau, have been utilized in various ways to make nutritional knowledge increasingly effective in maternal and child health activities. As summarized in a 1956 report:[2]

"Federal financial assistance has made it possible for States to augment local resources for maternal and child health services. Nearly all physicians, nurses, dentists, and other professional personnel engaged in maternal and child health work deal with nutrition as an integral part of a well-rounded program. To assure that nutrition problems are dealt with adequately, State and local health agencies use some of their Federal grants-in-aid for the employment of nutritionists to serve as consultants to professional workers who

[2] Interagency Committee 1956 Nutrition education and school lunch activities. U.S. Dept. of Agriculture, Agricultural Research Service, Publication ARS 62–3.

care for mothers and children. According to a recent estimate, approximately 200 nutrition positions have been created in State health departments, as compared with some 10 or 12 before Federal grants were made available. Of these 200, about 20 give full time to consultation to hospitals and other institutions.

"Federal funds from the Children's Bureau have been used by States to cover a large part of the cost of giving advanced training in public health nutrition in colleges and universities to nutritionists already in the employ of the State agency or to be employed on the completion of their training. Financial assistance and consultation have been given by the Children's Bureau to institutions of higher learning that are developing graduate programs for the special training of nutritionists."

The Independently Incorporated Nutrition Foundation. When organized in 1942, it stated its program as follows:

"The Nutrition Foundation is primarily concerned with advancing the science of nutrition. It will seek this end by activities such as these:

"Research projects which have an immediate bearing upon the war emergency, both for the armed forces and for civilian population,

"Research work which has a long-range value in providing basic information and guidance in the science of nutrition,

"Research studies in nutrition which have a direct bearing upon public health,

"Assistance in bridging the gaps between research findings and the channels through which such information may become effective."

The Enrichment Program. This offers a means of spreading the benefit of *one part* of the newer knowledge of nutrition with a promptness comparable to some sanitary reforms instead of by the slow process of educating every individual or family concerned. When specialists in sanitary science and the necessary administrative officers are convinced of the importance of some sanitary measure to the public health, often the reform can be put into effect by legislation, or administrative action, or the two together, so that every citizen then lives in a better sanitary environment whether or not he has been educated to the significance of the reform. Similarly it now seems that we as a people have (or had)

been living in a bad nutritional environment in that the bread almost universally used had been artificially impoverished of most of its thiamine through the over-refinement of white flour, and that now the leaders of thought in the nutrition field can by united effort have the thiamine restored to the bread supply so that all the people will get the benefit promptly. To us this seems sound so far as it goes. Realizing that what is projected is only a partial restoration, it yet seems well worth while; and that it may well be supported by all interested in nutrition.

Nutrition Education

Underlying all these and many other activities for the extension of nutritional knowledge is, of course, the regular teaching of nutrition in schools and colleges, and the extension of such teaching into social welfare agencies of many kinds and into the technical training for the medical, nursing, and public health professions.

The fact that better nutrition of the people is both an economic and an educational problem is further shown in the findings of Stiebeling and Phipard (1939).[3] When, having estimated individually the nutrient contents of a very large number of family dietaries, they grouped them as nutritionally "good," "fair," or "poor," it became quite clear (as indicated earlier in this Chapter) that in general more money spent for food means a larger proportion of good dietaries; but also that with the same amount spent for food some families get nutritionally good dietaries while some of their neighbors do not. For example, among (East South Central) city families with an expenditure (at 1939 price levels) of $2.50 a person a week for food, 32 per cent bought diets nutritionally "good," 31 per cent bought diets nutritionally "fair," and 37 per cent (at the same level of expenditure!) bought diets nutritionally "poor."

Even with the help of the enrichment program, it remains true that to a greater extent than in most economic and hygienic reforms, improvement in nutrition must be attained by the educational building up of new or improved habits of conscious choice in the individual citizen, the cumulative effect of which is recognized as consumer demand.

[3] Full reference among Suggested Readings, Chapter 20.

Thus the purchase of a dozen oranges or an extra quart of milk may confidently be expected to have a two-fold influence: (1) in the building of a higher level of nutritional wellbeing and resultant health and efficiency in the family or individual consumer; and (2) in the upbuilding of the agricultural industries which produce these articles of food.

Our everyday choices of food are probably among the most frequent and certainly among the most influential of the conscious choices that we make.

What serves us best is to accept wholeheartedly the guidance of the newer knowledge of nutrition, and to make a steady habit of acting upon this scientific guidance just as fully as circumstances permit. If to give to fruits, vegetables, and milk as large a place in the dietary as present nutritional knowledge shows desirable should involve turning over a new leaf in one's daily food practice, then let it be turned once for all: not grudgingly and hesitantly, not in a spirit of fussiness; but definitely and with cheerful thanks that science has shown us a way in which choices that we make every day can have unexpectedly far-reaching beneficial effects.

Such adoption of the newer knowledge leaves wide latitude for individual preference and for due consideration of economic conditions in the choice among fruits and vegetables; and also for choice among the different forms of milk (fresh, canned, and dried) and such of its products as sufficiently possess its nutritional characteristics,--fermented milk, cheese, cream, and ice cream.

As explained in a previous Chapter, we interpret findings now available as indicating that for the best results as much as half of the needed food calories should be taken in the form of fruit, vegetables, and milk in some form or forms. For those who do not find it feasible to plan their food in terms of calories, much the same result will usually be obtained if at least half the expenditure for food is for fruits, vegetables, milk, cheese, cream, and ice cream. To provide more fully for thiamine (vitamin B_1), and iron, we have recommended also that of such amounts of breadstuffs or cereals as one may choose to eat, at least half should be in the approximately "whole grain" forms; and we now add, "Let all white bread be enriched."

Note that this application of the new knowledge of nutrition leaves half the food (whether in terms of calories or of cost) to the

free choice of the individual. So there is ample room to "eat what you want while eating what you should." Yet for those who wish guidance in all of their expenditures for food, there is the U.S. Department of Agriculture publication, "Helping Families Plan Food Budgets," upon which we have drawn freely in Chapter 20.

One who has studied carefully the new scientific knowledge can get its benefit without necessarily renouncing any particular article or type of food. If on some days it is impracticable to make as modern a selection of food as is here recommended, one can even-up on some subsequent day or days. A moderate amount of such practice as the exercises suggested at the ends of the previous chapters will afford, taken thoughtfully, should enable one to acquire a sense of proportion in regard to foods and dietaries which will give the needed guidance without constant weighing, measuring, or calculation.

Recorded observations extending over a consecutive period of four years, leave the definite impression that one may eat among other people, accepting the food choices made by others to the full extent that business and social customs call for, not making oneself conspicuous or self-conscious, but so balancing in the meals which are under one's control (and in the choices which even conventional meals allow) that half of the total food calories will be taken in the form of fruits, vegetables, and milk, in accordance with the suggestion already made and discussed.

Freedom in the Choice of Food

An important factor in making nutritional knowledge fully effective is a realization that, as already explained in part, a wide freedom of choice of food is entirely compatible with the gaining of the benefits which the newer chemistry of nutrition offers.

Freeing of the mind from needless inhibitions in one's choices among foods helps one to a more effective use of scientific guidance in nutrition; and it is also worthwhile from the viewpoint of the pleasures of the palate. For, as an editorial writer as pointed out, beside the meeting of nutritional needs, "eating has an immense vogue as an amusement."

Religious inhibitions in the use of food do not fall within the scope of this book to discuss further than to say that the newer

knowledge of food values makes it easier to provide full nutritional equivalents for any particular article of food which may be interdicted.

Sanitary considerations may also be given all due weight without significantly hampering our food choices. Until recently, discussions of food and health have dwelt largely upon ways in which food may conceivably do injury. Public pressures for "pure food" legislation, and the resulting Federal and State laws, have been activated chiefly by fears of injury and fraud; and as embodied in statute have dealt mainly in prohibitions of adulteration and misbranding. If with these laws in operation too many people still harass themselves and hamper their use of nutritional knowledge by exaggerated fears of unsanitary qualities in food, it is because they do not yet fully realize that during the past thirty years, partly through the permanent accomplishments of the "pure food movement" and partly through the advances of nutritional knowledge, *the center of gravity of the problem of the relations of food to health and social welfare has shifted from sanitation to nutrition.*

This is not to say that all the sanitary problems of the food supply have been entirely solved. It is to say that sanitary practices and nutritional knowledge now stand at such points that the consumer who thinks of his food choices chiefly in terms of his fears is sadly behind the times; and that it is far wiser to think of our foods *primarily* in terms of what they can do *constructively* in the building of higher health. Inasmuch as the constructive health values of a scientific choice of foods have been considerably emphasized throughout this book we must assume that the reader will bear them in mind when we now mention the considerations which may occasionally tend to divert our food consciousness back into its old unhappy channels. Obviously, consumers may sometimes have occasion to assert themselves, either directly or through their local health officers, in regard to proper standards of municipal housekeeping cleanliness in the retail handling of foods. Thirty to forty years ago there was need of greater cleanliness in slaughterhouses and on dairy farms; during the intervening years the conditions formerly complained of have been very generally corrected.

In America at least, the sanitary conditions surrounding the production and handling of milk have been so greatly improved and

are now so carefully and constantly safeguarded by the health authorities of most communities that the consumer need no longer feel any special anxiety regarding the safety of the market milk supply.

Under the United States meat inspection law, Federal inspection of animals for slaughter and of the sanitary conditions of handling meat, governs the operations of establishments which engage in interstate commerce in meats or meat products. This inspection is quite thorough in most respects; but the Federal authorities have not found it feasible to include the microscopic examinations which would be necessary to exclude pork which is infested with trichinae. Nor have any local health officers, so far as we know. The consumer's protection from trichinosis depends, therefore, on individual insistence upon very thorough cooking of the flesh of swine in whatever form it is eaten. (Current reports of frequency of trichinosis indicate that this precaution is not yet as fully appreciated as it should be.)

Meat of local origin, which has not been subject to Federal inspection, must, of course, depend upon local standards for its sanitary safeguards.

In former years, there was much controversy as to what preservative substances might be added to foods and under what conditions. The question (or group of questions,—for each preservative should of course be judged individually after investigation on its own merits) was studied in considerable detail by the U.S. Department of Agriculture, both in its laboratories in Washington and through consultants working in their own laboratories in several universities; and the rulings based on the findings of these investigations have been followed for a generation in the enforcement of the food laws without giving rise to any serious difference of legal or scientific opinion. Hence the question of preservatives may presumably be regarded as having been settled in the sense that it need no longer be carried as anxiety in the mind of the consumer, or bias one's choice of food.

Spray residues on fruits and vegetables constitute, however, a somewhat analogous problem which is not yet (1956) settled in the same sense. Until less-toxic sprays or more thorough methods of commercial washing to remove spray residues are introduced, it may be wise for the consumer either to reject the entire skin of

sprayed fruits and vegetables or to scrub very thoroughly in washing such foods before eating, and also to remove by means of a knife all parts which cannot be effectively reached in scrubbing. Spray residues thus constitute a part of a larger problem as to whether any of the supposed improvers used in food technology leave anything in the food which may be deleterious when consumed almost daily over a lifetime.

The government seems now (1956) to be taking more seriously any sanitary hazards of present-day food supply as may conceivably be of such nature as to interfere seriously with the choice of foods for their nutritive values.

Food allergies, which render the people afflicted with them abnormally sensitive to foods which are perfectly wholesome to normal people, may seriously handicap food choices in relatively rare cases. The services of a physician who specializes in allergy may be required to determine whether a person who thinks he "cannot eat" some important article or type of food is suffering from a real allergy or only from an aversion.

In the vast majority of cases (in peacetime, at least) the dominant limitation upon the choice of food is lack of money to buy as much as all members of the family would like to eat of the foods of their choice. Here, education in the newer aspects of the nutritive values can do much to assist the individual or the family to get the maximum of satisfaction for the food expenditure, as we have sought to explain in the preceding Chapter and the earlier pages of this one.

Further Consideration of Consumer Demand and the Consequent Adjustment of Food Production

There need be no fear about the ability of our farms to supply the extra fruit, vegetables, and milk that will be called for as more and more consumers shift the emphasis of their food choice in the direction which our newer knowledge of nutrition indicates.

We are informed by experts of the United States Department of Agriculture that the farmers of this country could readily increase many-fold their present production of practically any fruit or vegetable for which there is sufficient growth of consumer demand. Land and labor formerly devoted too exclusively to the growing of

cotton, and for which diversification is now universally recognized as needed on grounds of business economics in any case, may well be devoted, in part or in rotation, to the growing of small fruits, melons, and fresh vegetables (often referred to in agricultural and economic terms as "truck crops"). Here there is an enormous potential resource for the meeting of a growing market demand for fruits and vegetables; and the growth of such consumer demand will be favorable to the farmer in two ways, by relieving him from financial dependence upon a single cash crop and by greatly improving the home-grown food supply of the farm family.

Moreover, according to the findings of Dr. O. E. Baker (long of the U.S. Department of Agriculture), fruit occupies only from 1 to 2 per cent, and vegetables only about 4 per cent of the crop acreage in this country, so that production of both could be doubled or trebled without affecting the returns from other crops to any serious degree.

Some regions and some breeds of cattle are adapted to the production of meat and others to the production of milk. This country has enough of the former to ensure an abundant meat supply in any case; but it is also true that there are enormous areas of our most productive farm lands which can and do produce both meat and milk, and shift their emphasis toward the one or the other "according to the market," i.e., to the consumer demand.

There are also other regions in which the most profitable agricultural alternatives are meat on the one hand and some fruit or vegetable on the other; e.g., apples in the Northwest; and lettuce in Colorado, where they still speak of the partially converted cattlemen "who want to sow their lettuce-seed from the saddle."

The federal agricultural experts have also made careful estimates of the relative amounts of human food produced by a given acreage of farm land, with separate consideration of plowed land and pasture land when animal production is involved. To enter fully into this important study of our present and potential food production resources would lead beyond the scope of this book.[4] It suffices for our present purpose to say that fruits, vegetables, and milk are

[4] One of the present writers has discussed more fully the food problems just mentioned in two other books: Sherman's *Food Products*, 4th Ed. (Macmillan), and Sherman's *Foods: Their Values and Management* (Columbia University Press).

more advantageous crops for the farmer to produce (even if they require more attention) than are their usual alternatives, so that the increasing emphasis upon these foods can not only be amply met by our farmers but will also be distinctly helpful to the normal evolution of American agriculture.

Nutrition Policy on an International Scale

The past decade or so has seen phenomenal growth of a worldwide nutrition program, attacking on an international front the sorts of problems of nutrition policy which have been considered earlier on a more limited scale: the scientific problem of determining the needs for optimal nutrition and translating these into terms of foods people know and will eat; the agricultural and technological problem of providing and distributing the needed foods; the economic problem of enabling consumers to purchase these; and the cultural and educational problem of persuading people to eat them.

These efforts have been directed and coordinated through several agencies of the United Nations, working with local governmental authorities, often with the assistance of independent philanthropic and/or research institutes.[5]

Soon after the organization of the United Nations, its subsidiary Food and Agriculture Organization (FAO) met in Quebec (October 1945) and defined its objectives in the following terms:

"The primary objective of the nations united in the Food and Agriculture Organization is to raise levels of nutrition throughout the world, to ensure not only that all peoples are freed from the danger of starvation and famine but that they obtain the kind of diet essential for health. It is the responsibility of Member nations to take the steps necessary for attaining this objective, and the responsibility of FAO to assist them by all possible means." Thus, even at a time when a large portion of the world's population faced near-starvation as a result of the war emergency, the FAO set the goal of promoting higher health through better nutrition. To this

[5] An illustration of such outside assistance is the recent announcement of a grant by the Rockefeller Foundation for the support of research, by United Nations agencies and the National Research Council of the United States, to guide programs to prevent protein malnutrition, especially in areas such as India, Central America, and Africa.

end the *World Food Survey*, prepared by this agency in 1946 from data supplied for 70 countries and representing about 90 per cent of the world's population, included estimates not only on pre-war food consumption but also on what the food consumption ought to be in order to provide adequate nutrition for full health. These latter "nutritional targets" varied somewhat from one nation to another of the earth's population, according to what was deemed *practicable of attainment with reasonable promptness*, taking full account of national food customs and economic conditions. Assisting underdeveloped countries toward the attainment of these targets, whether by improved methods of agriculture, or of food technology, or by other means, has been a continuing principal objective of the Food and Agriculture Organization.

Also concerned with international nutrition policy is the World Health Organization (WHO), "a specialized agency of the United Nations" which "represents the culmination of efforts to establish a single intergovernmental health agency. As such, it inherits the functions of antecedent organizations such as . . . the Health Organization of the League of Nations." It includes (in its scope of activities too numerous to list): maternal and child health, nutrition, professional and technical training, biological standardization, etc., thus overlapping at several points the objectives and operations of the FAO. As soon noted officially:

"Almost every practical program of nutrition has aspects which fall within the fields of interest of both FAO and WHO. Collaboration must therefore be flexible and no sharp dividing lines of responsibility can be drawn. Close working relationships between the nutrition workers in both secretariats are of essential importance."

To insure this, the Joint FAO/WHO Expert Committee on Nutrition was created, and held its first full session in Geneva in October 1949.[6]

It is this Joint Committee which has been coordinating investigation into protein malnutrition in many parts of the earth, as already noted in Chapter 6. Besides long-range planning for such improved food supplies as may eradicate the disease, an immediate attack on

[6] The report of this first meeting appeared in 1951 as WHO Technical Report Series No. 16; later reports as No. 44 (1952), No. 72 (1953), No. 97 (1955). (Distributed by Columbia University Press, International Documents Service.)

the practical problem especially in infants and children was initiated through the widespread distribution of dried skimmed milk made available by still another United Nations agency, the United Nations International Children's Emergency Fund (UNICEF). An effort is being made, through these various agencies, to develop other high-quality-protein-rich foods which will be practicable to produce locally and acceptable to the populace. Examples of the latter include fish flour, soya milk, and soya milk powder.

The recent large-scale test in the Philippines of the effectiveness of enriched rice in combatting beriberi was another project sponsored jointly by FAO and WHO with the financial support of the Williams-Waterman Fund for the Combat of Dietary Diseases (see Chapter 12).

An indication of the breadth of the international nutrition program which the Joint FAO/WHO Expert Committee on Nutrition has undertaken in collaboration with local governmental and independent agencies is contained in the following listing of problems under consideration of the Committee at the time of its 1955 *Report:*

requirements for calories, requirements for protein, protein-rich foods for feeding infants and children, enrichment of dried skimmed milk with vitamins A and D, additives to food, education and training in nutrition, pellagra, endemic goiter, nutrition and degenerative diseases, anthropometry applied to nutrition, assessment of nutritional status, and nutritional aspects of the welfare of the aged.

To what extent the findings developed in such a program will find implementation through governmental action, only time can tell. But, whatever part political policy or statesmanship may play, the science of nutrition will increasingly serve human progress through an ever better informed and more intelligent consumer demand in the daily choice and use of food.

This daily use of our science, alike to "illuminate the mind" and to "ameliorate man's estate," is an opportunity and a responsibility in which each of us has a share.

EXERCISE

Write your own supplement to the foregoing discussion of how to make nutritional knowledge more effective.

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Appendix A

FATTY ACIDS

With few exceptions the fatty acids of natural fats contain even numbers of carbon atoms; for both their building-up and breaking down processes go on mainly, if not entirely, by steps which add or remove a two-carbon "link" at a time.

Also these fatty acids belong, so far as known, to one or another of five series: the saturated series, of which stearic acid is an example, in which the molecule has no "double bond"; the series which includes oleic acid, which is unsaturated to the extent of one double bond in the molecule, and three further-unsaturated series with, respectively, two, three, and four double bonds in the molecule.

All statements regarding the *occurrence* of fatty acids in fats are to be understood as meaning that the acid occurs as *glyceride* (triglyceride), perhaps accompanied by a trace of the same acid in a free state.

Saturated Fatty Acids

The saturated fatty acids constitute an homologous series of the type formula $C_nH_{2n}O_2$. The nutritionally important members of this series are:

Butyric acid, $CH_3\ (CH_2)_2\ COOH$ (or more simply written $C_4H_8O_2$), occurring chiefly in butter fat of which it constitutes about 5 to 6 per cent;

Caproic acid, $C_6H_{12}O_2$, occurring in milk fats and coconut oil;[1]

Caprylic acid, $C_8H_{16}O_2$, which also occurs in milk fats and coconut oil;

Capric acid, $C_{10}H_{20}O_2$, occurring in the fats of milk (butter), of the coconut, and of the spice bush;

Lauric acid, $C_{12}H_{24}O_2$, which occurs in butter, coconut and palm oils, and in higher proportion in the fat of the spice bush;

Myristic acid, $C_{14}H_{28}O_2$, which also occurs in the fats just named, and in small proportions in many plant and animal fats;

[1] As the melting point of coconut fat lies between ordinary temperate and tropical temperatures, this commodity is an oil as shipped from the Tropics which produce it while it is a soft solid when it appears in such markets as London and New York.

Palmitic acid, $C_{16}H_{32}O_2$, which occurs widely and abundantly in both animal and vegetable fats;

Stearic acid, $C_{18}H_{36}O_2$, which also is widely distributed in both plant and animal fats, more abundantly in the hard fats of both groups. (While *stearin* as a scientific term is the name for the individual chemical substance, glyceryl tristearate, the triglyceride of stearic acid alone; the harder portion of a fat as pressed industrially may in commerce be called its stearin, *e.g.*, "beef stearin," "cottonseed stearin," etc.); and

Arachidic acid, $C_{20}H_{40}O_2$, which takes its name from peanut oil, has also been found in several other food fats.

Unsaturated Fatty Acids

The best known fatty acids of the series $C_nH_{2n-2}O_2$ are:

Oleic acid, $C_{18}H_{34}O_2$, which occurs in nearly all fats and fatty oils; and

Erucic acid, $C_{22}H_{42}O_2$, long known as occurring in the seed fats of the cruciferous plants such as commercial rapeseed and mustardseed oils, and more recently found to occur also in marine animal oils.

Acids of the series $C_nH_{2n-4}O_2$, $C_nH_{2n-6}O_2$, and $C_nH_{2n-8}O_2$ are illustrated respectively by *linoleic acid*, $C_{18}H_{32}O_2$; *linolenic acid*, $C_{18}H_{30}O_2$; and *arachidonic acid*, $C_{20}H_{32}O_2$. These are the best known members of their respective series; but probably many others exist in nature. It is also quite probable that these well-established names may sometimes be applied inadvertently to unidentified isomers as well as to the individual substances originally isolated and named.

In the earlier chemical investigations of natural fats small amounts of these highly unsaturated fatty acids were doubtless often overlooked. Now that their apparent nutritional importance is stimulating reinvestigation they are being found more widely distributed than previously reported, and new members are being added to this group.

Appendix B

DIGESTIVE ENZYMES

The Chief Digestive Enzymes and Their Actions

	Enzymes	Secreted by	Action in normal digestion
Act on Carbohydrates	Ptyalin (salivary amylase	Salivary glands	Converts starch to maltose
	Amylopsin (pancreatic amylase)	Pancreas	Converts starch to maltose
	Invertase (Sucrase)	Intestinal mucosa	Converts sucrose to glucose and fructose
	Maltase	Intestinal mucosa	Converts maltose to glucose
	Lactase	Intestinal mucosa	Converts lactose to glucose and galactose
Act on Fats	Lipases	Gastric mucosa, intestinal mucosa, and pancreas	Split fats to fatty acids, monoglycerides, and/or glycerol
Act on Proteins	Pepsin	Gastric mucosa	Splits proteins to proteoses and peptones
	Trypsin, Chymotrypsin	Pancreas	Split proteins and some intermediate products to polypeptides
	Carboxypeptidase	Pancreas	Split peptides to amino acids
	(A battery of) Peptidases	Intestinal mucosa	

Appendix C

COMPOSITION AND NUTRITIVE VALUES OF FOODS

In the tabulations which follow, the nutrients are stated per 100 grams of the edible food material (also sometimes written per 100 gm. E.P.).

Table 46 shows the approximate dimensions of a 100 gram portion of nearly every food included; then the number of Calories as computed by the "more specific" factors (see Chapter 4); followed by the percentage by weight of protein, fat, and carbohydrate, respectively.

Table 47 shows, for nearly every food included therein: the milligrams of calcium, phosphorus, iron, ascorbic acid (vitamin C), thiamine (vitamin B_1), riboflavin, and niacin; and the International Units of vitamin A value: each per 100 grams of the edible material.

The chief source of the data on nutrient values in these tables is *Agriculture Handbook Number* 8, published by the U.S. Department of Agriculture in June 1950. Tables 46 and 47 list a few foods not included in the Department's table, some taken from earlier editions of this book, a few from Bowes and Church's *Food Values of Portions Commonly Used*, 8th Edition, 1956.

It should be remembered that, even in the case of "natural" raw foods, there are variations in composition from sample to sample; that further (and in the case of some nutrients, substantial) differences may be introduced by the homemaker's practices in cooking and otherwise preparing foods for the table; and, of course, that recipes for "made" dishes vary somewhat from cook to cook. The average nutrient values given in these tables, and the approximations for estimating the size of a portion which provides 100 grams of edible material, are therefore not to be regarded as too rigidly precise. They should, however, help the users of this book to appraise the general nutritive quality of practical dietaries without resort to weighing of portions and analysis of samples.

Those who have occasion to make many such calculations will find it helpful to consult such other tables of food composition as are given in *Agriculture Handbook Number 8*, *Rose's Laboratory Handbook for Dietetics*, and Bowes and Church's *Food Values of Portions Commonly Used*, in which nutrients are reported also in terms of weights of foods as purchased (A.P.), and in terms of common household units; and in which a larger selection of food items are listed, including many more "made dishes" than the tables of this book.

TABLE 46. *Protein, Fat, and Carbohydrate Content and Energy Value of Foods: Expressed per 100 Grams of the Edible Material*

Food	Approximate Measure	Energy Value	Protein	Fat	Carbo-hydrate
		Calories	*grams*	*grams*	*grams*
Almonds	3/4 c.	597	18.6	54.1	19.6
Apple, raw	1 small, 2″ diam.	58	0.3	0.4	14.9
baked	1/2 large	150	0.4	0.5	36.0
Apple pie	3″ sector, 9″ diam.	246	2.1	9.5	39.5
Apple sauce	3/8 c.	72	0.2	0.1	19.7
Apricots, fresh	2–3 av.	51	1.0	0.1	12.9
dried	1/2 c. packed	262	5.2	0.4	66.9
Asparagus	8–12 stalks, 5″ long	21	2.2	0.2	3.9
Avocado	1/2, 4″ long	245	1.7	26.4	5.1
Bacon, raw	4–5 slices, 10″ long	630	9.1	65.0	1.1
cooked	14 slices	607	25.0	55.0	1.0
Bananas	1, 6 1/2″ long	88	1.2	0.2	23.0
Barley, pearled	1/2 c.	349	8.2	1.0	78.8
Beans, dry	1/2 c.	338	21.4	1.6	61.6
baked, with pork and molasses	1/2 c.	125	5.8	3.0	19.2
Lima, fresh	5/8 c.	128	7.5	0.8	23.5
dry	2/3 c.	333	20.7	1.3	61.6
snap or string	3/4 c., 1″ pieces	35	2.4	0.2	7.7
Beef, corned, canned	3 slices, 3″ × 2 1/2″ × 1/4″	216	25.3	12.0	0
dried or chipped	7 thin slices, 4″ × 5″	203	34.3	6.3	0
hamburger, raw		321	16.0	28.0	0
cooked	1 1/4 large patty	364	22.0	30.0	0

Beef, round, lean, raw		182	19.5	11.0	0
cooked	3″ × 3″ × ½″	233	27.0	13.0	0
Beet (s)	½ c., diced	42	1.6	0.1	9.6
Beet greens	½ c., after cooking	27	2.0	0.3	5.6
Biscuit, baking powder	5 small	342	8.2	10.6	52.2
Blackberries	¾ c.	57	1.2	1.0	12.5
Blueberries	¾ c.	61	0.6	0.6	15.1
Bologna	3½ slices, 4½″ diam. × ⅛″	221	14.8	15.9	3.6
Brazil nuts		646	14.4	65.9	11.0
Bread, Boston brown	2 slices, 3″ diam., ⅞″ thick	219	4.8	2.1	46.0
raisin	4–5 slices	284	7.1	3.1	57.8
white, enriched*	4–5 slices	275	8.5	3.2	51.8
whole wheat	4–5 slices	240	9.3	2.6	49.0
Broccoli	⅞ c., after cooking	29	3.3	0.2	5.5
Brussels sprouts	7 sprouts, 1½″ diam.	47	4.4	0.5	8.9
Buns	2/3 av.	339	9.4	7.2	59.1
Butter	½ c. scant; or 10 sq. 1¼″ × 1¼″ × ¼″	716	0.6	81.0	0.4
Buttermilk, cultured	½ c. scant	36	3.5	0.1	5.1
Cabbage	1½ c. chopped, raw	24	1.4	0.2	5.3
Cake, angel	⅕ av. cake	270	8.4	0.3	58.7
foundation, plain	1 pc., 3″ × 3″ × 1¾″	350	5.9	11.7	55.9
iced		342	5.0	9.3	60.4
fruit, dark	5 slices, 3″ × 3″ × ¼″	354	5.2	13.8	55.9
Cantaloupe	¼ melon, 5″ diam.	20	0.6	0.2	4.6
Carrots	¾ c., ½″ cubes	42	1.2	0.3	9.3
Cashew nuts	¾ c.	578	18.5	48.2	27.0
Cauliflower	1 c., chopped	25	2.4	0.2	4.9
Celery	4 medium stalks	18	1.3	0.2	3.7

* With 4% non-fat milk solids.

TABLE 46. *Protein, Fat, and Carbohydrate Content and Energy Value of Foods: Expressed per 100 Grams of the Edible Material* (Continued)

Food	*Approximate Measure*	*Energy Value*	*Protein*	*Fat*	*Carbo-hydrate*
		Calories	*grams*	*grams*	*grams*
Chard	1/3 c., after cooking	21	1.4	0.2	4.4
Cheese, Cheddar type	7/8 c., grated	398	25.0	32.2	2.1
cottage, skim milk	5 1/2 tbsp.	95	19.5	0.5	2.0
cream		371	9.0	37.0	2.0
Cherries	2/3 c.	61	1.1	0.5	14.8
Chestnuts		242	6.2	5.4	42.1
Chicken, roasting, raw		200	20.2	12.6	0
cooked	3 slices, 3 1/2″ × 2 1/2″ × 1/4″	198	28.3	(8.6)	0
Cocoa, dry		293	(8.0)	23.8	48.9
beverage, made with all milk	3/8 c.	95	3.8	4.6	10.9
Cod, fresh		74	16.5	0.4	0
Coleslaw	1 1/4 c.	86	1.3	6.1	7.7
Collards	1/2 c., after cooking	40	3.9	0.6	7.2
Corn, sweet	1 medium ear	92	3.7	1.2	20.5
canned	3/8 c.	67	2.0	0.5	16.1
Cornflakes	3 c.	385	8.1	0.4	85.0
Cornmeal, degermed, uncooked	2/3 c.	363	7.9	1.2	78.4
cooked	3/8 c.	50	1.1	0.2	10.7
Corn syrup	1/4 c.	340	0.0	0.0	85.0
Crabmeat	2/3 c.	104	16.9	2.9	1.3
Crackers, Graham	16 crackers	393	8.0	10.0	74.3
soda	14 crackers	420	9.6	9.6	72.7

Cranberries	1 c.	48	0.4	0.7	11.3
Cream, thin, 20% fat	3/8 c.	204	2.9	20.0	4.0
heavy, whipping, 35% fat	3/8 c.	330	2.3	35.0	3.2
Cucumbers	14 slices, 1/8″ thick, 2″ diam.	12	0.7	0.1	2.7
Currants, dried		322	2.4	1.7	74.2
fresh		55	1.2	0.2	13.6
Custard pie	2″ sector, 9″ diam.	204	5.2	8.7	26.3
Dandelion greens	1/2 c., after cooking	44	2.7	0.7	8.8
Dates, dried	14 av.	284	2.2	0.6	75.4
Egg(s), fresh, whole	2 medium	162	12.8	11.5	0.7
white	3 1/2 whites	50	10.8	0	0.8
yolk	6 1/2 yolks	361	16.3	31.9	0.7
Endive (Escarole)		20	1.6	0.2	4.0
Farina, uncooked	2/3 c.	370	10.9	0.8	77.4
cooked	3/8 c.	44	1.3	0.1	9.1
Figs, raw	3, 1 1/2″ diam.	79	1.4	0.4	19.6
Filberts	1/2 c.	702	15.6	65.3	13.0
Flounder, "sole"		68	14.9	0.5	0
Flour, white, enriched	7/8 c., sifted	364	10.5	1.0	76.1
whole wheat	3/4 c.	333	13.3	2.0	71.0
Frankfurter, raw		257	14.2	20.5	2.7
cooked	2 av., 5 1/2″ long, 3/4″ diam.	248	14.0	20.0	2.0
Grapefruit	1/2, 4″ diam.	40	0.5	0.2	10.1
Grapes	20 good-sized (1/2 c.)	70	1.4	1.4	14.9
Grapejuice	1/2 c., scant	67	0.4	0	18.2
Haddock, raw	1 pc., 3″ × 3″ × 1/2″	79	18.2	0.1	0
fried	1 pc., 3″ × 3″ × 1/2″	158	18.7	5.5	7.0
Halibut, raw	1 pc., 3″ × 2″ × 1″	126	18.6	5.2	0
broiled		182	26.2	7.8	0

TABLE 46. *Protein, Fat, and Carbohydrate Content and Energy Value of Foods: Expressed per 100 Grams of the Edible Material* (Continued)

Food	Approximate Measure	Energy Value	Protein	Fat	Carbohydrate
		Calories	grams	grams	grams
Ham, smoked, med. fat, raw	4½″ × 4″ × ⅜″	389	16.9	35.0	(0.3)
cooked	3 slices, 4¾″ × 4″ × ⅜″	397	23.0	33.0	(0.4)
Heart		108	16.9	3.7	0.7
Herring, smoked, kippered		211	22.2	12.9	0
Honey	¼ c.	294	0.3	0	79.5
Ice cream, plain	½ c.	207	4.0	12.5	20.6
Jams, marmalades, preserves	5 tbsp.	278	0.5	0.3	70.8
Kale	½ c., after cooking	40	3.9	0.6	7.2
Kidney	½ c., cubed	141	15.0	8.1	0.9
Kohlrabi	½–¾ c., diced	30	2.1	0.1	6.7
Lamb, leg, med. fat, raw	4″ × 3″ × ⅜″	235	18.0	17.5	0
roasted	2 slices, 4″ × 3¼″ × ⅛″	274	24.0	19.0	0
Lard	½ c.	902	0	100.0	0
Lemon juice	½ c.	24	0.4	0.2	7.7
Lettuce	6 large leaves	15	1.2	0.2	2.9
Liver, beef		136	19.7	3.2	6.0
Lobster, canned	⅔ c. meat	92	18.4	1.3	0.4
Macaroni, uncooked	1 c., or 10 sticks 9″ long	377	12.8	1.4	76.5
baked with cheese	⅜ c.	211	8.1	11.0	19.7
Macaroons	8 av.	424	6.5	15.2	65.2
Mackerel, raw	1 pc., 4″ × 1½″ × 1″	188	18.7	12.0	0
canned		182	19.3	11.1	0

Margarine	½ c., scant; or 10 sq. 1¼″ × 1¼″ × ¼″	720	0.6	81.0	0.4
Mayonnaise	½ c.	708	1.5	78.0	3.0
Milk, fluid, whole	⅜ c.	68	3.5	3.9	4.9
non-fat (skim)	⅜ c.	36	3.5	0.1	5.1
condensed (sweetened)	⅓ c.	320	8.1	8.4	54.8
evaporated	½ c.	138	7.0	7.9	9.9
dried, skimmed	1 c.	362	35.6	1.0	52.0
whole	1 c.	492	25.8	26.7	38.0
malted, dry	¾ c.	407	14.6	8.5	70.7
beverage	⅜ c.	104	4.6	4.4	11.8
Mince pie	3″ sector, 9″ diam.	252	2.5	6.9	45.6
Molasses, medium dark	5 tbsp.	232	—	—	60.0
Muffins	2 medium	280	8.0	8.4	42.1
Mushrooms, fresh, raw	10 small or 4 large	16	2.4	0.3	4.0
canned, solids and liquid	⅜ c.	11	1.4	0.2	3.7
Mustard greens	½ c. after cooking	22	2.3	0.3	4.0
Oatmeal, uncooked	1¼ c.	390	14.2	7.4	68.2
cooked	⅜ c.	63	2.3	1.2	11.0
Okra	10–12 pods	32	1.8	0.2	7.4
Olives, green		132	1.5	13.5	4.0
Onions, mature	3, 1½″ diam.	45	1.4	0.2	10.3
Oranges	1, 2½″ diam.	45	0.9	0.2	11.2
Oysters, meat only	5–8 med., ⅜ c.	84	9.8	2.1	5.6
Parsnips	½ c., cubed	78	1.5	0.5	18.2
Peaches, raw	1 medium	46	0.5	0.1	12.0
canned in syrup	1 large half plus 1½ tbsp. juice	68	0.4	0.1	18.2
dried		265	3.0	0.6	69.4
Peanut(s), roasted	¾ c., shelled	559	26.9	44.2	23.6
Peanut butter	6 tbsp.	576	26.1	47.8	21.0

TABLE 46. *Protein, Fat, and Carbohydrate Content and Energy Value of Foods: Expressed per 100 Grams of the Edible Material* (Continued)

Food	*Approximate Measure*	*Energy Value*	*Protein*	*Fat*	*Carbo-hydrate*
		Calories	*grams*	*grams*	*grams*
Pears, fresh	1 large	63	0.7	0.4	15.8
Peas, fresh, green	¾ c., shelled	98	6.7	0.4	17.7
mature, split	½ c.	344	24.5	1.0	61.7
Pecans	¾ c.	696	9.4	73.0	13.0
Peppers, green	1, 3–4″ long	25	1.2	0.2	5.7
Pineapple, canned in syrup	2 slices, 3 tbsp. juice	78	0.4	0.1	21.1
fresh	½ c., diced	52	0.4	0.2	13.7
Plums	3, 1½″ diam.	50	0.7	0.2	12.9
Pork, loin chops, med. fat, raw	1, 3½″ × 3″ × ¾″	296	16.4	25.0	0
cooked	2 small	333	23.0	26.0	0
fresh ham, raw	1 piece, 4″ × 3½″ × ⅜″	344	15.2	31.0	0
cooked	3 slices, 4″ × 2½″ × ⅛″	400	24.0	33.0	0
sausage, raw		450	10.8	44.8	0
cooked	2 patties, 2¼″ diam.	470	17.5	44.0	0
Potato(es), raw	1, 2½″ diam.	83	2.0	0.1	19.1
cooked, baked	1, 2¼″ diam.	98	2.4	0.1	22.5
French fried	20 pieces, 2″ × ½″ × ½″	393	5.4	19.1	52.0
mashed with milk and butter	½ c.	123	2.1	6.0	15.9
Potato chips	50 pieces, 2″ diam.	544	6.7	37.1	49.1
Prunes, dried, uncooked	12 medium	268	2.3	0.6	71.0
Radishes	10 red button	20	1.2	0.1	4.2
Raisins, dried	⅝ c.	268	2.3	0.5	71.2

Raspberries, red	$\frac{3}{4}$ c.	57	1.2	0.4	13.8
Rice, uncooked	$\frac{1}{2}$ c.	362	7.6	0.3	79.4
cooked	$\frac{2}{3}$ c.	119	2.5	0.1	26.2
Rutabagas	$\frac{2}{3}$ c., $\frac{1}{2}''$ cubes	38	1.1	0.1	8.9
Salmon, canned	$\frac{2}{3}$ c.	173	20.2	9.6	0
Sardines, canned in oil, drained	2 pc., $3'' \times 1\frac{1}{2}'' \times 1''$	214	25.7	11.0	1.2
Sauerkraut, solids	$\frac{2}{3}$ c.	22	1.4	0.3	4.4
Scallops, raw	$\frac{1}{2}$–$\frac{2}{3}$ c.	78	14.8	0.1	3.4
fried	3–4 med. pieces	295	16.4	19.6	13.3
Shad	Cross section, $3\frac{1}{2}''$ on back	168	18.7	9.8	0
Shad roe		128	20.9	3.8	2.6
Shredded wheat	$3\frac{1}{3}$ large biscuits	360	10.1	2.5	80.1
Shrimp, canned, drained	8–12 shrimp	127	26.8	1.4	0

TABLE 46. *Protein, Fat, and Carbohydrate Content and Energy Value of Foods: Expressed per 100 Grams of the Edible Material* (Continued)

Food	*Approximate Measure*	*Energy Value*	*Protein*	*Fat*	*Carbohydrate*
		Calories	*grams*	*grams*	*grams*
Soups, canned, condensed, chicken	⅓, 11 oz. can	60	2.7	1.9	7.9
cream of asparagus, celery, mushroom, condensed	⅓, 11 oz. can	90	2.2	5.2	9.5
green pea, condensed	⅓, 11 oz. can	114	5.2	1.6	20.4
tomato, condensed	⅓, 11 oz. can	74	1.8	1.8	14.6
vegetable, condensed	⅓, 11 oz. can	65	3.3	1.4	11.5
Soybean flour, flakes, grits, med. fat		264	42.5	6.5	37.2
Spaghetti, see Macaroni					
Spinach	½ c., after cooking	20	2.3	0.3	3.2
Squash, summer	½ c., mashed	16	0.6	0.1	3.9
winter	½ c., mashed	38	1.5	0.3	8.8
Squash pie	2″ sector, 9″ diam.	180	4.4	8.4	21.7
Strawberries, fresh	½–⅔ c.	37	0.8	0.5	8.3
frozen (sugar added)	½ c.	106	0.6	0.4	26.6
Sugar, brown, dark	½ c., packed	370	0	0	95.5
white	½ c.	385	0	0	99.5
Sweetpotato, raw	1 small or ½ large	123	1.8	0.7	27.9
baked	1 small or ½ large	152	2.2	0.9	34.4
candied	1 half, 3¾″ × 2¼″	179	1.5	3.6	36.2
Swordfish, raw		118	19.2	4.0	0
Tangerines	2, 2″ diam.	44	0.8	0.3	10.9
Tapioca, dry	½ c.	360	0.6	0.2	86.4
Tomatoes	1, 2½″ diam.; ½ c. stewed	20	1.0	0.3	4.0
Tuna, canned, drained	⅝ c.	198	29.0	8.2	0

Turkey, medium fat, raw		268	20.1	20.2	0
roasted	3 slices, 3½″ × 2½″ × ¼″	200	30.9	7.6	0
Turnip(s)	¾ c., ½″ cubes	32	1.1	0.2	7.1
Turnip greens	½ c., after cooking	30	2.9	0.4	5.4
Veal cutlet, raw	4″ × 2½″ × ½″	164	19.5	9.0	0
cooked		219	28.0	11.0	0
Walnuts, English	1 c. halves	654	15.0	64.4	15.6
Watercress		18	1.7	0.3	3.3
Watermelon	1 slice, 2½″ × 2½″ × 1″	28	0.5	0.2	6.9
Wheat germ		361	25.2	10.0	49.5
White sauce	⅓ c., generous	162	1.0	12.5	8.8
Yeast, baker's compressed		86	10.6	0.4	13.0
brewer's, dried		273	36.9	1.6	37.4

Table 47. *Approximate Averages of Mineral and Vitamin Values in Foods: per 100 Grams Edible Material*

Food	Calcium	Phosphorus	Iron	Ascorbic Acid, Vitamin C	Thiamine, Vitamin B_1	Riboflavin	Niacin	Vitamin A Value
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*I.U.*
Almonds	254	475	4.4	tr.	0.25	0.67	4.6	0
Apple, raw	6	10	0.3	5	.04	.03	0.2	90
baked	6	12	0.4	2	.02	.02	0.2	90
Apple pie	7	24	0.4	1	.03	.02	0.2	160
Apple sauce	4	8	0.4	1	.02	.01	tr.	30
Apricots, fresh	16	23	0.5	7	.03	.05	0.8	2790
dried	86	119	4.9	12	.01	.16	3.3	7430
Asparagus	21	62	0.9	33	.16	.19	1.4	1000
Avocado	10	38	0.6	16	.06	.13	1.1	290
Bacon, raw	13	108	0.8	0	.38	.12	1.9	(0)
cooked	25	255	3.3	0	.48	.31	4.8	(0)
Bananas	8	28	0.6	10	.04	.05	0.7	430
Barley, pearled	16	189	(2.0)	0	.12	.08	3.1	(0)
Beans, dry	163	437	6.9	2	.67	.23	2.2	0
baked, with pork and molasses	56	113	2.1	2	.05	.04	0.5	30
Lima, fresh	63	158	2.3	32	.21	.11	1.4	280
dry, mature	68	381	7.5	2	.48	.18	2.0	0
snap or string	65	44	1.1	19	.08	.11	0.5	630
Beef, corned, canned	20	106	4.3	0	.02	.24	3.4	(0)
dried or chipped	20	404	5.1	0	.07	.32	3.8	(0)

hamburger, raw	9	128	2.4	0	.07	.14	3.8	(0)
cooked	9	158	2.8	0	.08	.19	4.8	(0)
round, lean, raw	11	180	2.9	0	.08	.17	4.7	(0)
cooked	11	224	3.4	0	.08	.22	5.5	(0)
Beet(s)	27	43	1.0	10	.02	.05	0.4	20
Beet greens, raw	118[a]	45	3.2	34	.08	.18	0.4	6700
Biscuit, baking powder	218	193	1.8	0	.23	.22	2.0	0
Blackberries	32	32	0.9	21	.04	.04	0.4	200
Blueberries	16	13	0.8	16	(.02)	(.02)	(0.3)	280
Bologna	(9)	(112)	2.2	0	.18	.19	2.7	(0)
Brazil nuts	186	693	3.4	—	.86	—	—	tr.
Bread, Boston brown	185	158	2.5	0	.08	.12	1.4	140
white, enriched,[b] 2% non-fat milk solids	65	81	1.8	0	.24	.15	2.2	0
4% non-fat milk solids	79	92	1.8	0	.24	.15	2.2	0
6% non-fat milk solids	92	101	1.8	0	.24	.15	2.2	0
whole wheat	96	263	2.2	0	.30	.13	3.0	0
Broccoli, raw	130	76	1.3	118	.10	.21	1.1	3500
Brussels sprouts, raw	34	78	1.3	94	.08	.16	0.7	400
Butter	20	16	0	0	tr.	.01	0.1	3300[c]
Buttermilk, cultured from skim milk	(118)	93	0.1	1	.04	.18	0.1	tr.
Cabbage, raw	46	31	0.5	50	.06	.05	0.3	80
Cantaloupe	17	16	0.4	33	.05	.04	0.5	3420[d]

° Note: figures in parentheses are imputed values. A dash indicates insufficient basis for imputing a value although there is reason to believe a measurable amount of the constituent might be present.

[a] Calcium may not be available because of presence of oxalic acid.

[b] Iron, thiamine, riboflavin, and niacin are based on the minimum level of enrichment in standards of identity proposed by the Federal Security Agency and published in the Federal Register, August 3, 1943.

[c] Year-round average.

[d] Based on deeply colored varieties.

TABLE 47. *Approximate Averages of Mineral and Vitamin Values in Foods: per 100 Grams Edible Material* (Continued)

Food	*Calcium*	*Phosphorus*	*Iron*	*Ascorbic Acid, Vitamin C*	*Thiamine, Vitamin B_1*	*Riboflavin*	*Niacin*	*Vitamin A Value*
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*I.U.*
Carrots	39	37	0.8	6	.06	.06	0.5	12000
Cashew nuts	46	428	5.0	—	.63	.19	2.1	—
Cauliflower, raw	22	72	1.1	69	.11	.10	0.6	90
Celery, bleached	50	40	0.5	7	.05	.04	0.4	0
Chard, raw	105[a]	36	2.5	38	.06	.07	0.4	2800
Cheese, Cheddar type	725	495	1.0	(0)	.02	.42	tr.	1400
cottage, skim milk	96	189	0.3	(0)	.02	.31	(0.1)	(20)
cream	68	97	0.2	(0)	(.01)	.22	0.1	(1450)
Cherries, fresh	18	20	0.4	8	.05	.06	0.4	620
canned	11	12	(0.3)	6	.03	.02	0.2	720
Chestnuts	34	90	0.8		.22			
Chicken, roasting, raw	14	200	1.5	(0)	.08	.16	8.0	(0)
cooked	20	280	2.1	(0)	.08	.18	9.0	(0)
Cocoa, dry	125[a]	712	11.6	(0)	.12	.38	2.3	(30)
beverage, made with all milk	119	114	0.4	1	.04	.19	0.2	160
Cod, fresh	10	194	0.4	2	.06	.09	2.2	0
Coleslaw	39	27	0.4	41	.05	.04	0.2	70
Collards, raw	249	58	1.6	100	.11	.27	(2.0)	6870
Corn, sweet, raw	9	120	0.5	12	.15	.12	1.7	390[e]
canned	4	51	0.5	5	.03	.05	0.9	200[e]

Cornflakes	11	58	1.3	(0)	.04	.10	1.6	(0)
Cornmeal, whole ground, dry	10	256	2.4	(0)	.38	.11	2.0	510[e]
degermed, unenriched, dry	6	99	1.1	(0)	.14	.05	1.0	300[e]
cooked	1	14	0.2	(0)	.02	.01	0.1	40[e]
degermed, enriched,[b] dry	6	99	2.9	(0)	.44	.26	3.5	300[e]
cooked	1	14	0.4	(0)	.06	.04	0.5	40[e]
Crabmeat	45	182	0.9	-	.05	.06	2.5	—
Crackers, Graham	20	203	1.9	(0)	.30	.12	1.5	(0)
soda	20	96	1.1	(0)	.06	.05	1.1	(0)
Cranberries	14	11	0.6	12	(.03)	(.02)	0.1	40
Cream, thin, 20% fat	97	77	0.1	1	.03	.14	0.1	830
heavy, whipping, 35% fat	78	61	0.1	1	.02	.11	0.1	1440
Cucumbers	10	21	0.3[f]	8	.03	.04	0.2	0[f]
Currants, fresh	36	33	0.9	36	.04	—	—	120
Custard pie	125	116	1.2	(0)	.05	.16	0.3	230
Dandelion greens	187	70	3.1	36	.19	.14	(0.8)	13650
Dates, dried	72	60	2.1	(0)	.09	.10	2.2	60
Egg(s), fresh, whole	54	210	2.7	0	.10	.29	0.1	1140
white	6	17	0.2	0	tr.	.26	(0.1)	(0)
yolk	147	586	7.2	0	.27	.35	tr.	3210
Endive (Escarole)	79	56	1.7	11	.07	.12	0.4	3000
Farina, unenriched, dry	28	112	1.0	(0)	.06	.06	0.8	0
cooked	3	13	0.1	(0)	.01	.01	0.1	0
enriched, dry	28	112	1.3[b]	(0)	.37[b]	.26[b]	1.3[b]	0
cooked	3	13	0.2	(0)	.04	.03	0.2	0
Figs	54	32	0.6	2	.06	.05	0.5	80
Filberts	287	354	4.1		.4	—	—	—

[e] Vitamin A value based on yellow corn; only a trace in white corn or cornmeal.

[f] Based on pared cucumbers; unpared contain about 1.2 mg. iron and 260 I.U. Vitamin A value per 100 gm.

TABLE 47. *Approximate Averages of Mineral and Vitamin Values in Foods: per 100 Grams Edible Material* (Continued)

Food	*Calcium*	*Phosphorus*	*Iron*	*Ascorbic Acid, Vitamin C*	*Thiamine, Vitamin B_1*	*Riboflavin*	*Niacin*	*Vitamin A Value*
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*I.U.*
Flour, white, unenriched	16	87	0.8	(0)	.06	.05	0.9	(0)
enriched	16	87	2.9[b]	(0)	.44[b]	.26[b]	3.5[b]	(0)
whole wheat	41	372	3.3	(0)	.55	.12	4.3	(0)
Frankfurter, raw	8	100	1.5	0	.18	.19	2.8	0
cooked	6	49	1.2	0	.16	.18	2.5	0
Grapefruit	22	18	0.2	40	.04	.02	0.2	tr.
Grapes	17	21	0.6	4	.06	.04	0.2	80
Grapejuice	10	10	0.3	tr.	.04	.05	(0.2)	—
Haddock, raw	23	197	0.7	—	.05	.08	2.4	—
fried	18	182	0.6	—	.04	.09	2.6	—
Halibut, raw	13	211	0.7	—	.07	.06	9.2	440
broiled	14	267	0.8	—	.06	.07	10.5	—
Ham, smoked, med. fat, raw	10	136	2.5	0	.70	.19	4.0	(0)
cooked	10	166	2.9	0	.54	.21	4.2	(0)
Heart	9	203	4.6	6	.58	.89	7.8	30
Herring, smoked, kippered	66	254	(1.4)		tr.	.28	(2.9)	0
Honey	5	16	0.9	4	tr.	.04	0.2	0
Ice cream, plain	123	99	0.1	1	.04	.19	0.1	520
Kale, raw	225	62	2.2	115	.10	.26	2.0	7540[g]
Kidney	9	221	7.9	13	.37	2.55	6.4	1150

Kohlrabi, raw	46	50	0.6	61	.06	.05	0.2	tr.
Lamb, leg, med. fat, raw	10	213	2.7	0	.16	.22	5.2	0
roasted	10	257	3.1	0	.14	.25	5.1	0
Lemon juice	14	11	0.1	50	.04	tr.	0.1	0
Lettuce, headed	22	25	0.5	8	.04	.08	0.2	540
loose-leaf	62	20	1.1	18	.04	.08	0.2	1620
Liver, beef	7	358	6.6	31	.26	3.33	13.7	43900
Lobster, canned	65	192	0.8		.03	.07	2.2	—
Macaroni, unenriched, raw	22	165	1.5	0	.09	.06	2.0	0
cooked	9	65	0.6	0	.02	.02	0.5	0
enriched, raw	22	165	2.9[b]	0	.88[b]	.37[b]	6.0[b]	0
cooked	9	65	1.1	0	.17	.10	1.4	0
baked with cheese	191	169	0.7	tr.	.10	.20	0.9	450
Mackerel, raw	5	239	1.0	—	.15	.35	8.4	(450)
canned	185	274	2.1	—	.06	.21	5.8	430
455 Margarine	20	16	0	0	0	0	0	3300[h]
Milk, fluid, whole	118	93	0.1	1	.04	.17	0.1	(160)
non-fat (skim)	123	97	0.1	1	.04	.18	0.1	tr.
condensed (sweetened)	273	228	0.2	1	.05	.39	0.2	(430)
dried, whole	949	728	0.6	6	.30	1.46	0.7	1400
non-fat	1300	1030	0.6	7	.35	1.96	1.1	(40)
evaporated	243	195	0.2	1	.05	.36	0.2	400
malted, dry	287	379	2.1	0	.33	.54		1020
beverage	135	123	0.3	1	.07	.21		250
Mince pie	16	40	2.2	1	.07	.04	0.4	10
Molasses, medium dark	290	69	6.0	—				
Muffins, made with enriched flour	206	191	1.6	0	.18	.21	1.5	100

[g] Other investigators have given much higher results for the vitamin A value of kale.

[h] Based on average vitamin A value of fortified margarine.

TABLE 47. *Approximate Averages of Mineral and Vitamin Values in Foods: per 100 Grams Edible Material* (Continued)

Food	*Calcium*	*Phosphorus*	*Iron*	*Ascorbic Acid, Vitamin C*	*Thiamine, Vitamin B_1*	*Riboflavin*	*Niacin*	*Vitamin A Value*
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*I.U.*
Mushrooms, fresh, raw	9	115	1.0	5	.10	.44	4.9	0
canned, solids and liquid	7	90	0.8	—	.02	.25	2.0	0
Mustard greens, raw	220	38	2.9	102	.09	.20	0.8	6460
Oatmeal, uncooked	53	405	4.5	0	.60	.14	1.0	0
cooked	9	67	0.7	0	.10	.02	0.2	0
Okra	82	62	0.7	30	.08	.07	1.1	740
Olives, green	87	17	1.6	—	tr.	—	—	300
Onions, mature	32	44	0.5	9	.03	.04	0.2	50
Oranges	33	23	0.4	49	.08	.03	0.2	190
Oysters, meat only	94	143	5.6	—	.15	.20	1.2	320
Parsnips, raw	57	80	0.7	18	.08	.12	0.2	0
Peaches, raw	8	22	0.6	8	.02	.05	0.9	880
canned in syrup	5	14	0.4	4	.01	.02	0.7	450
dried	44	126	6.9	19	.01	.20	5.4	3250
Peanut(s), roasted	74	393	1.9	0	.30	.13	16.2	0
Peanut butter	74	393	1.9	0	.12	.13	16.2	0
Pears, fresh	13	16	0.3	4	.02	.04	0.1	20
Peas, fresh green, raw	22	122	1.9	26	.34	.16	2.7	680
canned	25	67	1.8	8	.11	.06	1.0	540
mature, split	33	268	5.1	2	.77	.28	3.1	370
Pecans	74	324	2.4	2	.72	.11	0.9	50

Peppers, green	11	25	0.4	120	.04	.07	0.4	630
Pineapple, canned in syrup	29	7	0.6	9	.07	.02	0.2	80
fresh	16	11	0.3	24	.08	.02	0.2	130
Plums	17	20	0.5	5	.06	.04	0.5	350
Pork, loin, med. fat, raw	10	186	2.5	0	.80	.19	4.3	0
cooked	11	235	3.0	0	.83	.24	5.0	0
fresh ham, raw	9	168	2.3	0	.74	.18	4.0	0
cooked	11	238	3.1	0	.53	.24	4.7	0
sausage, raw	6	100	1.6	0	.43	.17	2.3	0
cooked	10	175	2.0	0	.49	.24	3.0	0
Potato(es), raw	11	56	0.7	17[i]	.11	.04	1.2	20
cooked, baked	13	66	0.8	17	.11	.05	1.4	20
French fried	30	152	1.9	28	.18	.11	3.3	50
mashed with milk and butter	27	59	0.6	7	.08	.05	0.8	260
Potato chips	(30)	(152)	(1.9)	11	(.18)	(.11)	(3.2)	(50)
Prunes, dried, uncooked	54	85	3.9	3	.10	.16	1.7	1890
Radishes	37	31	1.0	24	.03	.02	0.3	30
Raisins, dried	78	129	3.3	tr.	.15	.08	0.5	50
Raspberries, red	40	37	0.9	24	.02	(.07)	(0.3)	130
Rice, brown, uncooked	39	303	2.0	0	.32	.05	4.6	0
converted, uncooked	24	136	0.8	0	.20	.03	3.8	0
cooked	8	43	0.3	0	.05	.01	1.1	0
white or milled, uncooked	24	136	0.8	0	.07	.03	1.6	0
cooked	8	45	0.3	0	.01	.01	0.4	0
Rutabagas, raw	55	41	0.4	36	.07	.08	0.9	330
Salmon, canned, solids and liquid, including bones	259[j]	344	1.2	0	.04	.16	7.3	230[k]

[i] Year round average. Recently dug potatoes, 24 mg. ascorbic acid per 100 gm. After 3 months storage, about 12 mg., and after 6 months storage, about 8 mg.

[j] Includes bones. If these are discarded, calcium content is much lower.

[k] Value is for red salmon. Vitamin A value of pink salmon is much less (about 70 I.U. per 100 grams).

TABLE 47. *Approximate Averages of Mineral and Vitamin Values in Foods: per 100 Grams Edible Material* (Continued)

Food	Calcium	Phosphorus	Iron	Ascorbic Acid, Vitamin C	Thiamine, Vitamin B_1	Riboflavin	Niacin	Vitamin A Value
	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.	I.U.
Sardines, canned in oil, drained	386	586	2.7	0	.02	.17	4.8	220
Sauerkraut, canned, solids	36	18	(0.5)	16	.03	.06	0.1	40
Scallops, raw	26	208	1.8	—	.04	.10	1.4	0
Shad	—	260	0.5	—	.15	.24	8.4	—
Shad roe	23	242	1.2	—	.25	—	—	2500
Shredded wheat	47	360	3.5	0	.22	.12	4.4	0
Shrimp, canned, solids only	115	263	3.1	0	.01	.03	2.2	60
Soups, canned, condensed, chicken	15	15	0.3	—	.02	.11	1.2	—
cream of asparagus, celery, mushroom, condensed	52	45	0.3	1	.04	.17	0.1	160
green pea, condensed	26	80	1.2	3	.14	.06	1.0	(360)
tomato, condensed	21	31	0.7	7	.02	.08	0.6	(1000)
vegetable, condensed	26	40	0.6	6	.04	.06	0.9	—
Soybean flour, flakes, grits, med. fat	244	610	13.0	0	.82	.34	2.6	110
Spaghetti, see Macaroni								
Spinach, raw	81[l]	55	3.0	59	.11	.20	0.6	9420
Squash, summer, raw	15	15	0.4	17	.05	.09	0.8	260
winter, raw	19	28	0.6	8	.05	.12	0.5	4950
Strawberries, fresh	28	27	0.8	60	.03	.07	0.3	60
frozen	22	22	0.6	41	.02	.05	0.2	40

Sugar, brown, dark	76	37	2.6	0	0	0	0	0
white	0	0	0	0	0	0	0	0
Sweetpotato, raw	30	49	0.7	22	.09	.05	0.6	7700[l]
baked	37	60	0.9	23	.10	.06	0.8	9510
candied	36	45	0.9	9	.04	.04	0.5	6250
Swordfish, raw	19	195	0.9		.05	.05	9.1	1580
Tangerines	(33)	(23)	(0.4)	31	(.07)	(.03)	(0.2)	(420)
Tapioca, dry	12	12	1.0	0	0	0	0	0
Tomato, fresh	11	27	0.6	23	.06	.04	0.5	1100
canned	(11)	(27)	(0.6)	16	.06	.03	0.7	1050
Tuna, canned, drained	(8)	(351)	1.4	0	.05	.12	12.8	80
Turkey, medium fat, raw	23	320	3.8	0	.09	.14	8.0	tr.
roasted	30	100	5.1	0	.08	.17	9.8	tr.
Turnip(s), raw	10	31	0.5	28	.05	.07	0.5	tr.
Turnip greens, raw	259	50	2.1	136	.09	.16	0.8	9540
Veal cutlet, raw	11	200	2.9	0	.14	.26	6.5	0
cooked	12	258	3.5	0	.08[m]	.28[m]	6.1[m]	0
Walnuts, English	83	380	2.1	3	.48	.13	1.2	30
Watercress	195	46	2.0	77	.08	.16	0.8	4720
Watermelon	7	12	0.2	6	.05	.05	0.2	590
Wheat germ	84	1096	8.1	0	2.05	.80	4.6	0
White sauce	115	95	0.1	tr.	.03	.15	0.1	510
Yeast, baker's compressed	25	605	4.9	0	.15	2.07	28.2	0
brewer's dried	106	1893	18.2	0	9.69	5.45	36.2	0

[l] If very pale varieties only were used, the vitamin A value would be very much lower.

[m] It is assumed that the veal is prepared by braising or pot roasting. Use of proportionate quantity of drippings would add approximately 50 per cent more thiamine and niacin and 25 per cent more riboflavin.

Appendix D

RECOMMENDED DIETARY ALLOWANCES

Table 48, with its accompanying footnotes, is reproduced from *Publication No. 302* of the National Research Council, 2101 Constitution Avenue, Washington, 25, D. C.

In the original publication may also be found a review of some of the evidence on which are based the expert judgments represented in the recommendations. It was pointed out that, "The Board recognizes a responsibility to explain as clearly as it can (even at the cost of some near-repetition) just how the levels of nutrient intake which it *recommends* are related to the lesser quantities which are essential to avoid manifest nutritional deficiencies. Studies on man, as well as more complete experience with animals, clearly indicate substantial improvements in growth and function when the intakes of certain nutrients are increased above the level which is just sufficient to prevent obvious deficiency symptoms. The level above which lesions or symptoms are not commonly observed is merely one point on a long curve relating intake to function. The allowance of a margin of intake above the critical level for each nutrient is, therefore, designed to permit additional benefits as well as to cover individual variations. No fixed formula for computing the margin between "minimal requirements" and "recommended allowances" would be equally logical for all nutrients or for all population groups. There is now much evidence from long-term animal experimentation that, aside from individual variations of need, the margins between optimal intake and minimal requirements are wider for some nutrients than for others. In the judgment of the Board substantially lower levels than those given in the accompanying table would not be expected to give equally good results with large numbers of people through long periods of time."[1]

[1] From page 5 of National Research Council *Reprint and Circular Series No. 129.*

TABLE 48. *Food and Nutrition Board, National Research Council Recommended Daily Dietary Allowances,*[1] *Revised 1953. Designed for the Maintenance of Good Nutrition of Healthy Persons in the U.S.A.* (Allowances are considered to apply to persons normally vigorous and living in temperate climate)

	Age Years	*Weight kgm. (lb.)*	*Height cm. (in.)*	*Calories*	*Protein, gm.*	*Calcium, gm.*	*Iron, mgm.*	*Vitamin A value, I.U.*	*Thiamine, mgm.*	*Riboflavin, mgm.*	*Niacin, mgm.*	*Ascorbic Acid, mgm.*	*Vitamin D, I.U.*
Men	25	65 (143)	170 (67)	3200[2]	65	0.8	12	5000	1.6	1.6	16	75	
	45	65 (143)	170 (67)	2900	65	0.8	12	5000	1.5	1.6	15	75	
	65	65 (143)	170 (67)	2600	65	0.8	12	5000	1.3	1.6	13	75	
Women	25	55 (121)	157 (62)	2300[2]	55	0.8	12	5000	1.2	1.4	12	70	
	45	55 (121)	157 (62)	2100	55	0.8	12	5000	1.1	1.4	11	70	
	65	55 (121)	157 (62)	1800	55	0.8	12	5000	1.0	1.4	10	70	
	Pregnant (3rd trimester)			Add 400	80	1.5	15	6000	1.5	2.0	15	100	400
	Lactating (850 ml. daily)			Add 1000	100	2.0	15	8000	1.5	2.5	15	150	400
Infants[3]	0–1/12[4]												
	1/12–3/12	6 (13)	60 (24)	kg. × 120	kg. × 3.5[3]	0.6	6	1500	0.3	0.4	3	30	400
	4/12–9/12	9 (20)	70 (28)	kg. × 110	kg. × 3.5[3]	0.8	6	1500	0.4	0.7	4	30	400
	10/12–1	10 (22)	75 (30)	kg. × 100	kg. × 3.5[3]	1.0	6	1500	0.5	0.9	5	30	400
Children	1–3	12 (27)	87 (34)	1200	40	1.0	7	2000	0.6	1.0	6	35	400
	4–6	18 (40)	109 (43)	1600	50	1.0	8	2500	0.8	1.2	8	50	400
	7–9	27 (59)	129 (51)	2000	60	1.0	10	3500	1.0	1.5	10	60	400
Boys	10–12	35 (78)	144 (57)	2500	70	1.2	12	4500	1.3	1.8	13	75	400
	13–15	49 (108)	163 (64)	3200	85	1.4	15	5000	1.6	2.1	16	90	400
	16–20	63 (139)	175 (69)	3800	100	1.4	15	5000	1.9	2.5	19	100	400
Girls	10–12	36 (79)	144 (57)	2300	70	1.2	12	4500	1.2	1.8	12	75	400
	13–15	49 (108)	160 (63)	2500	80	1.3	15	5000	1.3	2.0	13	80	400
	16–20	54 (120)	162 (64)	2400	75	1.3	15	5000	1.2	1.9	12	80	400

[1] In planning practical dietaries, the recommended allowances can be attained with a variety of common foods which will also provide other nutrient requirements less well known; the allowance levels are considered to cover individual variations among normal persons as they live in the United States subjected to ordinary environmental stresses.

[2] These calorie recommendations apply to the degree of activity for the reference man and woman described [as "fairly active," see Chapter 5]. For the urban "white-collar" worker they are probably excessive. In any case, the calorie allowance must be adjusted to the actual needs of the individual as required to achieve and maintain his desirable weight.

[3] The recommendations for infants pertain to nutrients derived primarily from cow's milk. If the milk from which the protein is derived is human milk or has been treated to render it more digestible, the allowance may be in the range of 2–3 gms. per kgm. There should be no question that human milk is a desirable source of nutrients for infants even though it may not provide the levels recommended for certain nutrients.

[4] During the first month of life, desirable allowances for many nutrients are dependent upon maturation of excretory and endocrine functions. Therefore no specific recommendations are given.

Appendix E

GLOSSARY[1]

absorption: taking up of water or materials in solution.

acetone substances: a group of substances often formed in the metabolism of fat (sometimes called "**acetone bodies**").

achlorhydria: lack of hydrochloric acid in gastric juice.

acidosis: any condition in which the body's alkaline reserve is depleted; may result from abnormal loss of alkaline salts from the body or (more commonly) from abnormal accumulation of acids. Term often used in restricted sense as synonymous with ketosis.

acrodynia: a disease of the skin.

actinomycetes: fungous microorganisms.

adipose: fatty or fat-storing.

adrenal (suprarenal) glands: a pair of endocrine glands, one being situated above each kidney, which secrete the hormone **adrenaline (epinephrine)**.

aerobic: acting in the presence of, and through the influence of, oxygen.

alanine: one of the digestion products of proteins.

alkaline reserve: the amount of potentially alkaline material available in the body to neutralize acids. Term often used in restricted sense as synonymous with the bicarbonate of the blood.

alkaline tide: increased alkalinity of the body generally and decreased acidity of the urine after a meal.

alkalosis: increased alkalinity in the body.

allergy: a condition of unusual or exaggerated specific susceptibility to a substance which is harmless in similar amounts for most individuals.

alveolar process: bony ridge containing tooth socket.

alveoli: membranous air sacs in the lungs.

aminopeptidase: an enzyme which disrupts peptides by attack at the end where the free amino group ($-NH_2$) is placed.

anaerobic: in absence of oxygen.

anaphylaxis: sensitization.

anorexia: lack or loss of appetite for food.

anoxia: deficiency of oxygen.

[1] Students please note that the Index should also be consulted, for, in general, terms which are explained in the text have not been included in the Glossary.

anthropology: the science of man, his origin, development, customs, beliefs, etc.

anthropometry: measurement of the size and proportions of the human body.

antibody response: production, in response of the introduction of a foreign body or protein (known as an **antigen**) into the blood stream, of specific proteins, known as **antibodies**, which tend to combine with and so nullify the effects of the foreign substance.

antineuritic: preventing neuritis.

antioxidant: a substance tending to prevent oxidative changes, such as the rancidification of fat.

antirachitic: preventing rickets.

antitoxin: specific agent against a toxin.

apatite: mineral with formula $[Ca_3(PO_4)_2]_3.CaX_2$, where X_2 may be any one of several negative ions, for example hydroxyl, in which case the compound is known as **hydroxyapatite**. The minerals of the bones and teeth have a composition similar to that of apatite.

appetite: the inclination or desire to eat; distinguished from hunger as the drive to eat.

arginine: one of the digestion products of proteins.

ariboflavinosis: riboflavin deficiency.

arteriosclerosis: "hardening of the arteries," i.e., abnormal thickening of the coats of the arteries, as by deposition of cholesterol, with resultant loss of elasticity.

aspartic acid: one of the digestion products of proteins.

atherosclerosis: one form of thickening of the walls of arteries.

atrophy: a wasting in size.

bacteriostatic: preventing or arresting the growth of bacteria.

base: a substance which combines with acids to form salts.

betaine: a nitrogenous base occurring in many natural foods, of nutritional interest as a source of "labile methyl" groupings.

bile: fluid secreted by the liver and poured into the intestines.

bile acids: acid substances (related in structure to the sterols) present as salts in bile and important in emulsifying fatty substances in the digestive tract.

biomicroscopy: literally, the study of a living object under the microscope. Used to denote a type of study of the eye thought to reveal signs of vitamin A deficiency.

biosynthesis: synthesis by a living organism.

bradycardia: abnormal slowness of the heart-beat.

Brassica: the cabbage family of plants.

bronchioles: minute branches of the bronchial tubes.

buffer: a substance which tends to prevent or minimize a change in the reaction of a solution.

calciferol: vitamin D_2; a form of antirachitic vitamin produced by irradiation of ergosterol.

calcification: the process by which tissue becomes hardened by a deposit of calcium salts within its substance.

calorigenic: heat-generating.

calorimeter: an instrument for measuring the heat change in any system.

carbon^{14}: a radioactive form of the element carbon, used as a tracer in metabolism studies.

carboxypeptidase: an enzyme which disrupts peptides by attack at the end where the free carboxyl group (—COOH) is placed.

carcinoma: a malignant tumor or cancer.

carcinogenic: cancer-producing.

cardiac: pertaining to the heart.

carotenes: yellow pigments having the formula $C_{40}H_{56}$, of which three modifications (alpha-, beta-, and gamma-carotene) serve nutritionally as precursors of vitamin A.

cartilage: the form of connective tissue commonly known as gristle.

casein: the principal protein of milk.

catalase: an iron-pyrrole-containing enzyme which catalyzes the decomposition of hydrogen peroxide into water and oxygen.

cephalin: a constituent of the brain; a substituted fat which contains phosphorus and nitrogen.

cerebrosides (galactolipids): constituents of brain and nerve substance which contain nitrogenous, fatty, and carbohydrate radicles.

cerebrospinal: pertaining to the brain and spinal cord.

chemotherapy: prevention or treatment of disease by means of chemical substances which act directly on the disease-producing agent.

chlorophyll: the green pigment of plants.

cholesterol: the principal sterol of animal origin.

choline: a nitrogenous base (containing "labile methyl" groupings).

chondroitin sulfate: a complex polysaccharide containing hexosamine, uronic acid, and sulfate groups, which is a principal constituent of cartilage.

cirrhosis: a disease characterized by excessive formation of connective tissue followed by contraction.

citrus: a genus of trees, including citron, grapefruit, lemon, lime, and orange.

clearance: the removal of a substance from the blood by the kidneys.

cocarboxylase: thiamine pyrophosphate, coenzyme in a decarboxylase enzyme system.

coenzyme: a specific nonprotein moiety essential to an enzyme system. Examples include **coenzymes I** and **II**, both niacin-containing compounds, which are coenzymes of dehydrogenase systems, **coenzyme A**, a pantothenic acid-containing compound involved in acetylation reactions, and so on.

collagen: a resistant protein which is a principal constituent of connective tissues, such as cartilage, and formation of which is affected by vitamin C deficiency.

colostrum: the secretion of the mammary glands a few days before or after birth.

congenital: existing at or from one's birth.

conjugate: a compound formed by the (temporary or reversible) joining together of two or more other compounds.

conjunctivitis: inflammation of the membranes which line the eyelids and cover the eyeball.

connective tissue: a tissue holding together and in place another, usually more active, tissue, as, for example, muscle fibers or the cells of glands.

constitution: an important but not well defined concept, perhaps usually understood as meaning that inherited potentiality of health which one can impair but cannot enhance. Recent work in nutrition is enabling us to take a less fatalistic and more constructively scientific attitude toward the individual health-potentiality which is partly the result of nutritional conditioning both before and after birth.

converted rice: white rice which has been processed in such a way as to carry significantly more thiamine than ordinary white rice.

cornea: the transparent external coat of the anterior (forward) portion of the eye, covering the iris and the pupil.

cornification: conversion into horny tissue.

coronary: pertaining to the arteries which supply the heart.

creatine: a methylated nitrogenous acetic acid which (combined as phosphocreatine) plays an important part in the processes of muscle contraction.

crown: that portion of the tooth which projects above the gum and is covered by enamel.

culture: growth or cultivation, as of bacteria or body tissues, especially in an artificial medium.

cysteine: the reduction product of cystine, which very readily becomes reoxidized to cystine.

cystine: one of the digestion products of proteins.

cytopenia: deficiency in the cellular elements of the blood.

deaminization: the process by which the amino group, $-NH_2$, is split out of a molecule, as deaminization of amino acids in metabolism.

death rate: the number of deaths (usually per 1000 individuals of total population) occurring within a given period of time (usually a year). **Specific death rates** are figured on the basis of the number of deaths reported in a given population: specific for age, race, sex, or a combination of such variables.

decarboxylation: the process by which the carboxyl group (—COOH) is split out of a molecule.

demineralization: excessive loss of inorganic salts, either from the body as a whole or from a particular tissue.

dentition: teething.

dermatitis: inflammation of the skin.

deuterium: hydrogen atom with twice the mass of ordinary hydrogen but otherwise resembling it in chemical and physiological properties. Such "heavy hydrogen" incorporated into compounds in place of part of the ordinary hydrogen may be used as a tracer in studies of intermediary metabolism.

dichotomy: division into two parts.

diuresis: increased secretion of urine.

dystrophy: literally, defective or faulty nutrition. Also defective or abnormal development or degeneration.

electrolyte: a substance which in aqueous solution breaks down into electrically charged particles known as ions.

endemic: peculiar to a particular people or region, as a disease which occurs more or less constantly in any locality.

endocrine: secreting internally or into the blood stream; as endocrine glands, or glands of internal secretion.

endogenous: originating within the organism.

environment: while usually suggesting surroundings, includes, by scientific definition, nutrition and any or all other *environmental factors*, that is everything that conditions the life-process except the hereditary or genetic factors. See also Internal environment.

epithelium: the covering of the skin and mucous membranes.

epinephrine (**adrenaline**): a hormone secreted by the adrenal glands.

ergosterol: a sterol found abundantly in fungi such as ergot and yeast and in very small amounts among the sterols of higher plants; on exposure to ultraviolet light of suitable wavelength it is converted into vitamin D_2.

ergothioneine: a sulfur-containing compound related to the amino acid histidine, found in red blood cells.

erythropoiesis: red blood cell formation. (Whence **erythropoietic.**)

estrus: period of heat or sexual excitement in the female of animals.

etiology: cause, or study of causes.

exogenous: originating outside the organism.

fibroblast: a connective tissue cell.

flavin: yellow-green fluorescent water-soluble pigment. The flavin of greatest interest in nutrition is riboflavin (vitamin G, lactoflavin, lactochrome).

flavoprotein: a compound containing riboflavin (or other flavin) and protein. Several flavoproteins are known as enzymes.

formyl: the radicle, HCO—, derived from formic acid.

gamma: (as unit of weight) microgram, i.e., one thousandth of a milligram.

gastric: pertaining to the stomach.

geriatrics: pertaining to aging, or to the aged.

germinal epithelium: layer of epithelial cells which is said to develop into the sperm cells in the male and into a mass of cells over the ovary in the female.

glutamic (glutaminic) acid: one of the digestion products of proteins.

glutathione: a substance containing glutamic acid, cysteine, and glycine which is found in active plant and animal tissues and is believed to play an important part in the oxidation and reduction reactions of the cells.

glycine (glycocoll): one of the digestion products of proteins.

glycolysis: breakdown of glycogen and related carbohydrates in processes which normally accompany the liberation of energy.

goitrogenic: goiter-producing.

gonadotrophic (gonadotropic): pertaining to substances (such as are formed in the hypophysis or the placenta) which affect the activity of the ovary or testis.

hardening of the arteries: a condition in which the arteries lose their normal elasticity through abnormal thickening of their coats, as by the deposition of cholesterol.

hematopoiesis: formation of blood. (Whence **hematopoietic.**)

hemeralopia: night blindness; condition in which a person sees more poorly at night or in a dim light than his normal vision would seem to warrant.

hemoglobin: the red protein found in the red blood cells; contains iron and is capable of uniting loosely with oxygen.

hemorrhage: (1) loss of blood; (2) any portion of blood which has escaped the blood vessels.

hexosamine: substance in which one hydroxyl group of a hexose has been replaced by an amino group.

hexose: any simple sugar containing six carbon atoms.

histidine: one of the digestion products of proteins.

histology: the branch of biology that deals with the minute structure of tissues.

homocysteine: a demethylated product of methionine. Capable of conversion to methionine in the animal body by a transmethylation reaction.

hydrocephalus: an increase in the volume of cerebrospinal fluid within the skull, resulting in enlargement of the head and great prominence of the forehead.

hydrolysis: a chemical change in which, with the introduction of the elements of water, a larger molecule is split into a smaller one or more.

hydroxyapatite: see apatite

hydroxyglutamic acid: one of the digestion products of proteins.

hydroxyproline: one of the digestion products of proteins.

hypercalcemia: abnormally high level of calcium in the blood.

hyperesthesia: excessive sensibility in receiving and feeling impressions of touch, temperature, pain, etc.

hyperplasia: abnormal multiplication of cells; the enlargement of a part of the body resulting therefrom.

hypertension: abnormally high tension, especially high blood pressure.

hypertrophy: excessive growth of an organ or tissue.

hypervitaminosis: a condition due to the administration of excessive amounts of a vitamin.

hypochromic: characterized by deficiency of pigment, specifically of hemoglobin.

hypophysis: the pituitary gland.

hypoplasia: abnormal deficiency of cells or structural elements; underdevelopment of a part of the body.

hypopotassemia: abnormally low level of potassium in the blood.

hypoprothrombinemia: subnormal blood level of prothrombin.

hypovitaminosis: condition due to insufficient supply of one or more vitamins.

idiopathy: abnormality which is "self-originating" in the sense that it is not referable to any evident cause.

imbalance: lack of balance.

inanition: a pathological state of body due to lack of any foodstuff (including water) which is essential to the living organism; perhaps most often used to refer to conditions resulting from insufficient caloric intake.

inositol: a cylic alcohol, $C_6H_6(OH)_6 \cdot 2H_2O$, found in various body tissues and sometimes regarded as a vitamin.

insulin: the active substance of the internal secretion of the pancreas.

intercellular: between the cells.

intermediary metabolism: the transfers and chemical changes undergone by nutrients after digestion and absorption.

internal environment: the resultant condition within the living body of all factors other than those which are directly hereditary. While most that has hitherto been written regarding the internal environment emphasizes its relative constancy, we are now learning that it is very importantly influenced by nutrition.

intravenous: into a vein.

in vitro: (literally "in glass") in a test-tube or other laboratory apparatus as contrasted with

in vivo: in the living organism.

ion: electrically charged atom or group of atoms such as is formed when an electrolyte is dissolved in water.

irritability: ability to respond to a stimulus.

isocaloric: having the same energy value.

isoleucine: one of the digestion products of proteins.

isomers: chemically different substances having the same empirical formula.

isotope: a form of an element which has the same atomic number as another but a different atomic weight. Thus, ordinary hydrogen has an atomic number of one and an atomic weight of one, while another isotope, H^2 or deuterium, has an atomic number of one but an atomic weight of two and yet another isotope, H^3 or tritium, has an atomic weight of three and an atomic number of one. See also radioactive isotope.

keratin: a very insoluble protein which forms the base of epidermis, hair, and of all horny tissues.

keratomalacia: softening of the cornea.

keratosis: an overgrowth of horny epithelium.

ketosis: a condition in which, due to the failure of the body to complete the oxidation of fatty acids, there is an abnormal accumulation of socalled "ketone bodies" (acetone, hydroxybutyric acid, and acetoacetic acid).

"labile methyl": a methyl ($-CH_3$) grouping which in metabolism may be transferred as a unit from one compound to another, as from methionine to choline.

lactalbumin: one of the proteins of milk.

lactic acid: a three-carbon organic acid ($CH_3CHOHCOOH$) formed as an intermediary in carbohydrate metabolism.

lecithin: a substance having the molecular structure of a fat in which one of the fatty acid radicles is placed by phosphoric acid carrying choline (a nitrogenous base).

legume: a family of plants, including peas, beans, soybeans, lentils, etc.
leucine: one of the digestion products of proteins.
leukemia: (usually fatal) disease of the blood-forming organs, characterized by uncontrolled proliferation of white blood cells (leukocytes).
lignins: very complex substances occurring in the woody parts of plants. Though associated with celluloses and hemicelluloses, they differ in containing a large proportion of non-sugar components.
lipotropic: having a preventive or curative effect on the development of fatty livers.
longevity: length of life.
lymphatic: a vessel which carries lymph.
lysine: one of the digestion products of proteins.
lyxose: one of the pentose sugars.
macroscopic: seen with the naked eye.
maize: corn.
matrix: the intercellular portion of a tissue.
megaloblast: a particular type of large erythroblast (the latter being a hemoglobin-containing cell representing a stage in the development of red blood cells).
melalgia: pain in the hands and/or feet.
metaplasia: change of one kind of tissue into another.
methionine: one of the digestion products of proteins.
methyl: (methyl radicle, $-CH_3$) a grouping which may transfer as a unit in chemical reactions.
microcytic: characterized by abnormally small red blood cells.
microgram: one thousandth of a milligram.
mitosis: cell division.
morbidity: the quality of disease or of being diseased. Hence **morbidity rate**, the number of cases of a specific disease occurring in a given population within a specified time.
morphological: having to do with structure and form.
mortality rate: death rate
myocardium: the muscular tissue of the heart.
neurasthenia: nervous exhaustion, extreme abnormal fatigability.
neutrality: the state of being neither acid nor alkaline.
nitrogen^{15}: isotope of nitrogen having atomic weight of 15 (as compared with the usual form which has an atomic weight of 14); used as a tracer in studies of nitrogen metabolism.
nucleic acid: a substance (so named because it is an essential constituent of cell nuclei) containing phosphoric acid, a pentose sugar, purine bases, and pyrimidine bases.

nutriture (nutritional status): term denoting all aspects of the body's condition of nutrition.

obesity: excessive fatness or overweight.

ocular: pertaining to the eye.

optimal (adj.), **optimum** (noun): the best.

organic: containing the element carbon; however, carbon dioxide, carbonic acid, and the carbonates and bicarbonates are not ordinarily regarded as organic.

"original chromosomal endowment": the set of chromosomes with which the individual is endowed at conception.

osmotic pressure: a physico-chemical property shown by substances in solution. It is most clearly manifest in the phenomenon of **osmosis**, which occurs when the solution is separated from pure water (or from a solution containing less of the dissolved substance) by a socalled semipermeable membrane, through which can pass water but not the substances in solution. Under these conditions, water passes through the membrane into the (more concentrated) solution.

osteoporosis: enlargement of the spaces of bone, whereby a porous appearance is produced. The loss of bony substance results in brittleness or softness of the bones.

ovulation: the maturation of the egg cell or ovum and its escape from the ovary.

oxidation: a chemical process involving the addition of the element oxygen to a compound, or the removal of the element hydrogen from the compound, or a chemically analogous change.

oxidation potential: a measure of the property of inducing oxidative changes.

parakeratosis: an abnormality of the horny layer of the skin.

parathyroid: group of small glands situated near the thyroid gland, and which secrete a hormone regulating calcium metabolism.

parenteral: not through the digestive tract.

pediatrics: pertaining to children or to development during childhood.

pentose: any simple sugar containing five carbon atoms.

periodontal: surrounding a tooth.

peripheral: relating to the portions of the body near the surface or in or near the extremities.

petechiae: tiny hemorrhage-spots, as in the skin.

pH: symbol used in expressing the relative acidity or alkalinity of a solution, so defined that pH 7.0 represents neutrality, pH less than 7.0 represents acidity (the lower the value the greater the acidity)

while pH greater than 7.0 represents alkalinity (the degree of alkalinity increasing with numerical value).

pharmacodynamic: related to the effects of medicine, as contrasted with those of food.

phenylalanine: one of the digestion products of proteins.

phosphatase: an enzyme which catalyzes the splitting off of phosphate groups from certain compounds.

phosphate: salt of phosphoric acid, H_3PO_4. Salts of the type BH_2PO_4 in which only one hydrogen has been replaced by reaction with base are called *mono-* or *primary* or *acid* phosphates; salts of the type B_2HPO_4 are called *di-* or *secondary* or *basic*.

phospholipids (phospholipins, phosphatids): substituted fats containing nitrogen and phosphorus.

photochemical: pertaining to chemical action produced as a result of light.

phytase: enzyme catalyzing the breakdown of phytic acid into inositol and phosphoric acid.

placenta: the organ on the wall of the uterus to which the embryo is attached by the umbilical cord and through which it receives its nourishment.

plaque: a patch, as, for example the semitransparent film formed under certain conditions on teeth and containing mucin, colloidal matter, and bacteria.

plasma: the fluid (i.e., non-cellular) portion of the blood.

polyneuritis (multiple neuritis): inflammation of many nerves at once.

porphyrin: a pyrrole-derivative, one component of both hemoglobin and chlorophyll.

precursor: a substance which is converted into another. For example, the carotenes are precursors of vitamin A, as explained in the text.

proline: one of the digestion products of protein.

prosthetic group: a grouping that is combined with a simple protein to form a complex protein, as for example the pigmented group which combines with the simple protein globin to give hemoglobin. Also applied to the nonprotein component, or coenzyme, of certain enzyme systems.

protein balance: the relationship found by comparing the amounts of nitrogen entering and leaving the body.

prothrombin: a precursor of blood-clot.

protoplasm: the essential substance of both the cell body and nucleus of cells of animals and plants, regarded as the only form of matter in which the phenomena of life are manifested.

provitamin: a substance which may be converted into a vitamin; thus, the carotenes are provitamins A, ergosterol is a provitamin D.

psychosomatic: denoting a physical condition caused by or notably influenced by the emotional state of the patient.

purines: substances related to purine, $C_5H_4N_4$; including adenine, guanine, xanthine, hypoxanthine, and uric acid.

pyrimidines: substances related to pyrimidine, $C_4H_4N_2$; including cytosine, uracil, thymine.

pyrrole: a five-membered ring compound, C_4H_5N.

pyruvic acid: a three-carbon organic acid ($CH_3COCOOH$) formed as an intermediary in carbohydrate metabolism.

rachitogenic: rickets-producing.

radicle (radical): a characteristic constituent part of a substance; as the amino acid radicles in proteins.

radioactive isotope: an isotope exhibiting the properties of spontaneous decomposition with the emission of radiations, such as x-rays. Radioactive isotopes of some elements occur naturally while in the case of other elements radioactive isotopes can be produced by artificial means. Such radioactive isotopes, incorporated into molecules of compounds which are fed or injected, can be traced readily by means of the radiations of such "tagged" atoms, and so give indication of the metabolic fate of the injected compound. Hence the terms **radiocalcium, radioiron,** etc.

rationale: the fundamental reasons serving to account for something.

reduction: a chemical process involving the addition of the element hydrogen to a compound, or the removal of the element oxygen from the compound, or a chemically analogous change.

renal: pertaining to the kidney.

rennin: the milk-curdling enzyme of the gastric juice.

resorption: removal by absorption.

ribose: a pentose sugar.

salt: the product of the reaction of an acid with a base.

saturated: having all the atoms of a molecule so linked that no double or triple bonds exist between adjacent carbon atoms.

sclera: the dense white coating which covers the eyeball except for the portion covered by the cornea.

sclerosis: hardening, especially of a part by overgrowth of fibrous tissue, applied particularly to the arteries and the nervous system.

senility: the state of showing the characteristics of old age.

serine: one of the digestion products of proteins.

sphingomyelin: a phospholipid composed of phosphoric acid, choline, a nitrogenous base **sphingosine,** and a fatty acid.

sprue: a chronic disease characterized by diarrhea, weakness, emaciation, changes in the tongue, and anemia.

stannous: one type of ion of the metal tin.

sterols: a chemically related group of fat-soluble substances of very complex molecular structure; the provitamins D are important members of this group of substances.

subcutaneous: beneath the skin.

sublethal: less than fatal.

sulfur^{35}: a radioactive isotope of sulfur, having atomic weight of 35, as compared with 32 for the most abundant isotope.

syndrome: a group of symptoms and signs which, considered together, characterize a disease or lesion.

synthesis: building up from simpler substances, or an artificial as distinguished from a natural formation.

tachycardia: excessive rapidity of heart-beat.

tetany: a disease characterized by sudden, violent, involuntary contraction of the muscles of the extremities.

therapeutic: curative.

thermolabile: liable to be destroyed by heat.

thermostable: not liable to be destroyed by heat.

thiaminase: a specific thiamine-destroying enzyme.

threonine: one of the digestion products of proteins.

tonus (tone): a sustained state of partial activity such as exists in muscles at all times.

transaminase: an enzyme catalyzing **transamination**, the transfer of amino groups ($-NH_2$) from one compound to another or from one position to another within a compound.

Trichinae: nematode parasites, one of which, *T. spiralis*, is frequently found in a cyst in hog muscle. Human beings also may become infested with these parasites (the resulting disease being known as **trichinosis**) by eating under-cooked pork from hogs so affected.

tryptophan: one of the digestion products of proteins.

tyrosine: one of the digestion products of proteins.

ultraviolet rays: rays of light of slightly shorter wave-length than visible light.

unsaturated: having within the molecule double or triple bonds, as between carbon atoms, to which, under proper conditions, hydrogen or certain other elements may be added.

urea: the principal nitrogenous end-product of the metabolism of proteins in the body.

uronic acid: any one of a number of acids closely related to simple sugars but having a carboxyl group in place of an alcoholic group.

valine: one of the digestion products of proteins.

vascularization: the process of becoming "full of" blood vessels. It may be entirely normal as in the ends of the long bones; or clearly a de-

parture from normal as when the whites of one's eyes become "bloodshot;" or there may be a doubtful zone between normal and abnormal vascularization as in the cornea where a degree of vascularization previously considered a normal variation is now considered by some to be a sign of riboflavin deficiency.

whey: the watery portion separating from the curd when milk coagulates, as in souring or cheesemaking.

xanthine: one of the purine bases.

xanthurenic acid: a green pigment, apparently derived from tryptophan, which may be found in the urine in pyridoxine deficiency.

xerophthalmia: a dry and lustreless condition of the eyeball.

xerosis: lack of adequate moisture in a tissue.

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* Students may well consult the Glossary also.